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From d'Orbigny to the Devonian: some thoughts on the history of the stratotype concept

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Abstract – D'Orbigny's stratigraphic contributions were enormous, both practical and theoretical. In his practice, d'Orbigny realised the central importance of using fossil faunas to correlate strata across different countries. His '*succession chronologique des âges du monde*' (of 1852) recognised 5 periods and 27 stages (ignoring his '*époque actuelle*'). The great majority of the latter were from two Periods, Jurassic (stages 7 to 16) or Cretaceous (17 to 23). D'Orbigny described the palaeontological characteristics, and geographical extensions, of each. Some stages he based on countries he never visited and although he never specified '*stratotype*' localities, he referred to some as '*étalon*', '*le mieux*' or '*le plus beau*'. These leads proved crucial when, in the mid 20th century, stratigraphers realised that *definitions* of chrono-stratal units must be attempted. The first attempts at *typification* simply followed zoology, where a *type specimen* tries to define a central position within the morphological variation of a species. In 1962, an early attempt was made to define Jurassic stages by three *type horizons* at different *type localities* (or *stratotypes* as they were now called) for each. A central horizon was chosen as 'lectotype section' and upper and lower boundaries for each were defined elsewhere. In France, it was preferred to investigate original intentions at named localities, through *unit-stratotypes*. These allowed some nationalistic pride, since France was the home of so many d'Orbignyan stages. 1980 saw the publication *Les Étages français et leurs Stratotypes*. However, British Silurian stratigraphers had realised that such zoologically based concepts would produce conflict, when any defined upper boundary stratotype conflicted with the defined lower boundary of a superjacent unit. They suggested, from 1962, to define only lower boundaries, via 'golden spikes', at *basal-boundary stratotypes*. This was the method chosen for the basal Devonian stratotype at Klonk, Czech Republic, defined in 1972, and a method adopted globally from 1986. However, this was when correlations were still largely based on fossils. The explosion of so many other stratigraphies since, based on magnetic or chemical records, events etc, has produced a first reaction against the idea that such stratotypes should be so defined, while a second, potentially more major claim, is that any 'golden spike' concept may no longer 'glitter', as competing stratotype concepts may be holding back stratigraphic progress. ***To cite this article: Hugh S. Torrens, C. R. Palevol 1 (2002) 335–345.*** © 2002 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

History / stratotype / Devonian / basal boundary definitions

Résumé – Depuis d'Orbigny jusqu'au Dévonien : quelques considérations sur l'histoire du concept de stratotype. Les nombreuses et importantes contributions de d'Orbigny à la stratigraphie sont rappelées ici et les méthodes qu'il utilisait, ainsi que ses théories, discutées. L'auteur souligne la part cruciale prise par d'Orbigny dans l'histoire de la stratigraphie – et tout particulièrement à propos des roches jurassiques – par l'utilisation des fossiles pour déterminer l'âge des couches et corréler ces dernières d'une région à l'autre. ***Pour citer cet article : Hugh S. Torrens, C. R. Palevol 1 (2002) 335–345.*** © 2002 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

Histoire / stratotype / Dévonien / définitions de base des limites

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Version abrégée

Les contributions stratigraphiques de d'Orbigny sont énormes, tant sur le plan pratique que sur le plan théorique. Et c'est ce dernier qui a surtout retenu l'attention. Dans son système, d'Orbigny réalise l'importance que représente l'utilisation des faunes fossiles pour corréler les couches, d'une région à l'autre. Sa « succession chronologique des âges du monde » (de 1852) reconnaît cinq périodes et 27 étages : (si l'on feint d'ignorer son « époque actuelle »). La grande majorité de ces derniers appartiennent à deux périodes : le Jurassique (étages 7 à 16) ou le Crétacé (17 à 23). D'Orbigny a décrit les caractéristiques paléontologiques et les extensions géographiques de chacun d'entre eux. Certains étages sont fondés sur des régions qu'il n'a jamais visitées et, bien qu'il n'ait jamais détaillé les localités « stratotype », il se réfère à certaines d'entre elles en tant qu'« étalon » ou « la mieux » ou « la plus belle ».

Ceci est devenu crucial, lorsque au milieu du XX^{e} siècle, les stratigraphes réalisèrent qu'il fallait tenter des *définitions* d'unités chrono-stratigraphiques. Les premières tentatives de *typification* suivent simplement la zoologie, dans laquelle un spécimen type essaie de définir une position centrale au sein de la variation morphologique d'une espèce. En 1962, une première tentative fut réalisée pour définir les étages jurassiques au moyen de trois *horizons types* (ou *stratotypes* comme ils étaient nommés au départ) pour chacun. Un horizon central était choisi comme « section lectotype » et les limites supérieure et inférieure de chacun étaient définies ailleurs. En France, préférence fut donnée aux intentions originelles de localités désignées, au travers de *stratotypes unité*. Ceux-ci garantissaient un certain orgueil national, puisque la France était la patrie de tant d'étages de d'Orbigny. 1980 voit la publication des *Étages français et leurs stratotypes*. Mais les stratigraphes anglais du Silurien avaient réalisé que de tels concepts fondés zoologiquement engendreraient des conflits, quand telle limite supérieure définie de stratotype se heurterait à telle limite inférieure définie, d'une unité sus-jacente. Ils suggèrent, à partir de 1962, de ne définir que des limites inférieures, au travers de *golden spikes*, à des *basal-boundary stratotypes*. C'est la méthode qui fut choisie pour le stratotype de base du Dévonien à Klonk, République tchèque, défini en 1972, et c'est la méthode adoptée de par le monde depuis 1986.

Mais ceci était valable lorsque les corrélations étaient largement fondées sur les fossiles. En effet, l'explosion, depuis lors, de si nombreuses autres stratigraphies basées sur des analyses chimiques, magnétiques, événementielles, etc., a produit une première réaction contre l'idée que de tels stratotypes devaient être ainsi définis ; une seconde, potentiellement plus importante, est que, quelque concept *golden spike* que ce soit ne peut plus rayonner longtemps, puisque des concepts de stratotype concurrents peuvent freiner les progrès de la stratigraphie.

1. Introduction

Geologists first ponder two basic characters of rocks; their lithology and thence their lithostratigraphy, and their fossil, chemical or other constituents, which generate their bio-, chemo- or other stratigraphies. However, a more crucial question in geology is, or should be, what is the age of a particular rock and its position in time. Here, the precision with which such positions can be arbitrated is vital [48]. It was in considering such matters of time, and the possibilities of synchronising lithological units across Europe, that Alcide d'Orbigny played such a crucial part in the history of stratigraphy, especially with Jurassic rocks, with which this paper will be principally concerned. He did so by using fossils to arbitrate the ages of rocks. He strove to investigate the '*ordre chronologique des faunes fossiles*', since only this, '*basé sur une stratification rigoureusement observée [...] peut avancer les questions stratigraphiques et l'histoire de notre planète*' [20].

D'Orbigny's many contributions to stratigraphy have been well outlined in a recent bicentennial contribution [16]. D'Orbigny's methods and his more theoretical ideas in stratigraphy have also been discussed, especially by Monty [36], Rioult [42], and Tintant [46].

We can perhaps best understand how d'Orbigny envisaged the geographical definition of his Stages in practice by some examples:

> "*C'est pour obvier à ces contradictions entre le nom et le caractère des couches, que nous avons proposé celui d'étage Sinémurien, parce que cette dénomination n'indique aucun caractère paléontologique, ni minéralogique, spécial à des points isolés, mais qu'il vient du nom de la ville de Semur (Sinemurium), autour de laquelle ces couches, montrant un beau développement, peuvent offrir le type le plus complet, et un point réellement étalon pour l'étage*" [21].

D'Orbigny had confirmed how this stage was to be typologically regarded two years earlier when he wrote of the outcrops at Semur, "*où se trouve le meilleur type, un gisement que je puis regarder comme* étalon, *c'est-à-dire pouvant toujours servir de point de comparaison*" [19]. He used the same word of his choice of a French section for his new, now Cainozoic, stage, the Stampian [16].

From this it is clear that d'Orbigny even envisaged a close approximation to what some of today's geologists have been attempting since the 1960's, to try to define units of the stratigraphic column by designating what were soon-to-be called unit-stratotype sections. A list of

such French stratotypes, both those still valid, and those which have fallen into disuse, is given by De Wever et al [16].

2. Some problems

As the English geologist W.J. Arkell pointed out, d'Orbigny soon had one real influence. He persuaded many other geologists, but few outside France and Switzerland, to take up his ideas by adding even more stages to his lists to suit their own districts. However, as Arkell wrote, "by their ardour [these] disciples of d'Orbigny have entirely defeated his ends". Arkell also showed that a more serious criticism was that d'Orbigny had adopted stage names at some localities in countries foreign to him, particularly in England, without ascertaining exactly what those foreign names meant in their places of origin. Thus, "by adding -ien to names such as Kimmeridge, Portland, Oxford and Bath, d'Orbigny sought to change their meanings entirely, adapting them to suit the succession where he knew it best, in the North of France. The result is that many of his names refer to... vaguely-known [by d'Orbigny] successions in England, while his palaeontological definitions refer to the succession in France. [Since this could only produce confusion, Arkell advocated] there is strong justification for the movement to define [d'Orbigny's] stages so that they shall correspond with the strata developed at the localities after which they are named, and so with the strata bearing the same names previously" [6].

Arkell pointed out that this problem had been first discussed at International Geological Congresses in 1880 and 1883 but as 'no satisfactory conclusions were arrived at and, as no rules formulated, the results of the debates have been little heeded' [6].

1937 has entered the literature as the year in which "the concept of stratotype – a standard section for comparison – in stratigraphy was proposed independently of each other by N.P. Gerasimov and H. Hedberg" [37]. Gerasimov's paper was in Russian and concerned the Permian in the Urals. Hedberg, on the other hand, then published a stratigraphic section in northeastern Venezuela. Hedberg at least, here only pointed out that "an essential prerequisite in progress in the geological study of a region is the establishment of a standard stratigraphic section – a section in which there is general agreement as to the names and limits of stratigraphic units and in which these units are well exposed and in normal relation to overlying and underlying units" [25].

In so saying, Hedberg was doing little more than d'Orbigny had suggested, with his 'étalon' sections, many years before. Hedberg added, when discussing formations, that palaeontology and mineralogy should always be subordinated to lithology in their definition. This highlights that he was only trying here to define lithostratigraphical formations in a regional context. He never used the word stratotype, and attempted no chronostratigraphic analyses.

3. An International Commission on Stratigraphical Nomenclature proposed

In 1946, a more fundamental contribution was made again by Arkell [7]. He proposed that "an International Commission on Stratigraphic Nomenclature should be set up, charged with formulating a code of rules analogous to that which has brought order into zoological nomenclature". He drew up a draft set of rules and discussed how they might be applied to the Jurassic System in Europe. When discussing stages, he paid high tribute to d'Orbigny, writing how "the stratigraphic work that corresponds to Linnaeus' *Systema Naturae* (10th ed. 1758) [the starting point for zoological nomenclature] is unquestionably d'Orbigny's *Paléontologie française, Terrains jurassiques* (vol. 1, Céphalopodes, 1842–1851 – since reprinted, see [22]), in which the stages and zones were first enunciated and a complete stratigraphic system worked out for the Jurassic. The cataclysmic bias [45] of d'Orbigny's work cannot invalidate its results. The relevant part of the book is the *Resumé géologique: division des terrains jurassiques en étages* (p. 600 to the end), which was published in 1850. This year should, therefore be taken as the starting point of stage and zonal nomenclature" [7].

This paper duly inspired the creation of an International Commission on Stratigraphical Nomenclature [26], which has been busy ever since. It needed to be as the case histories of some of d'Orbigny's original stages proves.

4. More problems

In 1966, Desmond Donovan discussed the principles of stratigraphy in a thought-provoking book [18]. In this, he pointed out the enormous problems of drawing, for example, the boundary between just two stages, the Toarcian (based on Thouars) and the Bajocian (based on Bayeux). This was because so many different interpretations of each stage had arisen between 1850 and 1966. A great part of the problem arose because d'Orbigny himself had been inconsistent, in drawing

this boundary between 1850 and 1852. These stages he had proposed in 1850 for rocks then called Upper Lias by English and French geologists (= Toarcian) and Inferior Oolite (= Bajocian). He first drew this boundary on the basis of characteristic ammonites placed by him in each stage. Two years later, d'Orbigny defined each stage in three separate ways. First, by the stratigraphical position of each (i.e. above or below other rocks); second, by the fauna of each and third by the formations described by previous workers, which d'Orbigny now included in each stage.

Since the first could seldom contribute to any precise definition, Donovan pointed out we were left with the second and third criteria. The second corresponds to a method of definition based on hierarchical position while the third constituted a typological definition. With such varying possibilities, Donovan pointed out how unsurprising it was that contradictions were duly found between d'Orbigny's definitions, and so between hierarchical definitions versus typological ones. This was "because [d'Orbigny] did not realise that the faunal succession could be divided into zones and [because he was misled by] the fact that faunas replaced one another gradually" and were not cataclysmic, as he had assumed. D'Orbigny was here misled by this theoretical assumption. Donovan provided a diagram showing the different levels at which this single stage boundary had been placed in different places in Germany, France, Switzerland, and Britain. This showed how then current French and British usages were completely different. Thus, Bajocian rocks in one country were assigned to a quite different stage in the other, despite both being of the same age. Donovan concluded that something had to be done to solve these dilemmas but that there was "no sign at present of either side being willing to give in to the other" [18].

The Bajocian stage stratotype had just been the subject of a fine study dated 1964, one of the first in which this word was used. This, of what was claimed to be the original type-section, only demonstrated that such unit-stratotypes produced yet another problem. Study of this stratotype showed that the base of the Bajocian should have been taken at a much higher level that any previous authors had ever used [41].

5. The Bathonian stage: a case history

As an example of how things have evolved, we can take another of d'Orbigny's stages, one of those established on rocks in a country he never visited e.g. that based on Bath, England. This was founded on the work done there between 1791 and 1803 by William Smith (1769–1839), while canal building in that area. The stage Bathonian had been first named by the Belgian, Jean Baptist d'Omalius d'Halloy (1783–1875) [17]. That name was soon adopted by d'Orbigny, in January 1850, in his *Prodrome*, a book dedicated to the Geological Society of London, which had financially supported his *Paléontologie française*, and of which he had been elected a Foreign Member in 1845. So he now took the opportunity, in a section devoted to "*des publications suivant l'ordre chronologique des faunes fossiles*", to pay tribute to British geology:

> *"Il est certain que [...] l'Angleterre a devancé la France dans le classement stratigraphique des terrains et des étages ; elle a servi de type, de point de départ aux divisions qui sont générales sur le globe... Nous ne saurions donc trop louer ces travaux des savants anglais, véritables fondateurs de la géologie stratigraphique.* [He concluded that] *l'histoire chronologique du globe terrestre est positivement née sur le sol de l'Angleterre*" [20].

After the proposal to create an International Commission on Stratigraphic Nomenclature in 1954, the need soon arose to attempt the definition of stages. In the case of the Bathonian, the first model used was that already suggested as analogous by Arkell in 1946 and then by Hedberg, who in 1954 had noted how "type sections are essential controls to named stratigraphic units [...] just as type specimens are for biostratigraphic units" [26]. These were controlled by an International Commission on Zoological Nomenclature.

In 1962 at the first 'Colloque du Jurassique' at Luxembourg, Sylvester-Bradley [45] discussed "type sections of Bathonian, Portlandian and Purbeckian stages", basing these proposals on a model based on taxonomic usage. He was a member of the then British Mesozoic Committee and suggested that type sections should be held, by analogy with type specimens in zoology, to define the minimum contents of each stage but not its boundaries. Thus, to define a stage, he considered it necessary to designate three type horizons, each in a designated type locality; the main one as a 'lectotype section' would define the "minimum contents" of a stage, while two other 'reference sections' would attempt to define the basal and upper boundaries of each stage.

In the case of the Bathonian, Sylvester-Bradley suggested that the 'lectotype section' should be chosen in the Great Oolite Limestone at Brown's Folly, Bath, on the grounds of historical priority. However, as far as the lower boundary went, he could only state that he knew "of no locality in England that I would propose for choosing as a reference section", since the beds concerned were either highly condensed or, worse, not visible at outcrop. As for the upper boundary, he felt that "no reference section should be chosen until the

faunas across that stage boundary were better known" [44].

It was soon realised, at least amongst those involved with the British Jurassic, that any such 'lectotype section' would define merely a local lithology, but one which contained no chronologically significant fossils or any other such criteria. So, it was soon asked what was this lectotype section, if it was intended to be chronostratigraphic, attempting to define? They felt that any such definition needed above all to define something chronologically *useful*. Another problem, which Otto Schindewolf was soon to point out, was that it was also still unclear if separate stratotypes for chronostratigraphy, biostratigraphy and lithostratigraphy were also all needed [43]. This is a problem to which different countries have reacted in different ways, the French, for example, insisting in 1997 that stratotypes are needed for all categories of stratigraphic units [40].

6. Basal boundary, or 'golden spike', stratotypes

Therefore, what were later called basal-boundary stratotypes, were sought to solve the problems of attempting a single chronological definition for any complete stage by a single unit-stratotype. These were known in Anglophone circles as defined by 'golden spikes' (or *clous d'or*). In the case of the Bathonian, it was generally agreed that the basal zone of the Bathonian was the Zigzag zone and its basal subzone the Convergens subzone. But any attempt to rely on historical priority, and thus the Bath area, was vitiated by the near total lack of any adequate or permanent sections there which could even start to define such a horizon there. So, a potential stratotype was suggested in France, at a section at Bas Auran, France. Here the base of bed 23 in a section described by the Italian Carlo Sturani (1938–1975) in 1967 seemed to provide the most detailed biostratigraphy across the potential basal-boundary stratotype [47].

Derek Ager (1923–1993) believed that it was the British Mesozoic Committee that had first proposed such basal-boundary stratotypes [2]. He wrote how "British Jurassic workers have been particularly disillusioned about the [existing unit-] stratotype concept because [...] many of the classic Jurassic stages were derived from English place-names (like Kimmeridge and Bath) by a Frenchman (Alcide d'Orbigny) who had never visited England. The British Mesozoic Committee therefore found it impossible to accept [this] stratotype concept as it is usually proclaimed on the continent. They chose instead to define only one boundary (the lower) of each division and to define it by a 'golden spike'... driven into the most suitable horizon in the most appropriate section. This 'topless' fashion, as it has been called, has the immense advantage that the base of one division then automatically defines the top of the division below. There can be no further arguments about gaps or overlaps" [3].

7. Unit-stratotypes are instead promoted in France

In France, the home of d'Orbigny's stages, geologists were rightly, and understandably proud of his remarkable, if somewhat premature, creations. There they worked hard to establish all those stages, which had been based on French rocks in properly documented unit-stratotypes. These were still largely based on single sections at the localities from which the stages had taken their names, which were used to define more inclusive, and exact, unit-stratotypes. Thus, in 1962, the 'Comité français de stratigraphie' had supported the concept of unit-stratotypes. It had insisted nevertheless on the fact that the real problem lay in how the limits of stages were to be defined. It also recommended that other stratotypes be defined when/if a historically based stratotype should prove inadequate. In particular it thought it desirable to create commissions to study the precise definition of, and the precise demarcation of the limits of, each stage by the revision of their stratotypes [15].

This was in opposition to the basal boundary-stratotype concept, which was soon to come into vogue in Britain and other Anglophone countries. The simple difference between the two is explained diagrammatically by Hedberg [27]. Such work in France culminated in the publication there of a major work of synthesis in 1980, called *Les Étages français et leurs Stratotypes* [14]. This documented 44 such unit-stratotypes, from that for the Givetian (Middle Devonian) to that of the Redonian (Pliocene). A further list in this volume (pp. 286–289) recorded all other French stage names that were since "*tombés en désuétude*". These totalled a frightening 150.

Of these 44, only 17 (40%) now survive on today's *International Stratigraphic Chart* [39]. D'Orbigny's Stampian, for example, was no longer one of them. Of d'Orbigny's other original stages, 4 had now been elevated to System status, while another 12 remained in use as stages. Thus 16 of d'Orbigny's original 27, an impressive 60%, have survived. The Aptian, from the aptly named town of Apt in Vaucluse, South-East France, is one of them. This unit-stratotype has recently inspired these rather sad words:

"Alors que dans la lignée d'Hedberg [27], la pression des stratigraphes non francophones a fini par imposer le concept de section type de limite d'étage, et par là-même rejeté les nombreux stratotypes français au rang de curiosités historiques, il peut paraître paradoxal de porter encore quelque intérêt à ces derniers vestiges, d'ailleurs souvent en voie de disparition faute de protection appropriée" [10].

This *International Stratigraphic Chart* also records those Global Stratotype Sections and Points (= GSSPs), which have been accepted since 1986 by the International Union of Geological Sciences (= IUGS). The Aptian is not one of them...

8. GSSPs

This was merely a new name for the old lower boundary stratotype concept. This, as we have seen, had arisen from British deliberations in the 1960s on how best to define stratigraphic units. This concept had been widely accepted by many, if not all, national communities of geologists in the following decades. In 1973 Ager, one of those British geologists, claimed that the principle of the 'golden spike' had first been introduced in 1964 by the British Mesozoic Committee [3]. This was in his paper to *Nature* that stated "as a general principle, only the base of each stage should be regarded as fixed, preferably by reference to a specified point in a type section for the lowest zone" (of that stage) [2]. In fact, even he had published this idea earlier, when his same Committee had "recommended, as a general principle, that the base of each stage should be regarded as fixed for all time (preferably by reference to a specified point in a type section)... This principle would aid greatly the stability of stratigraphical nomenclature" [1].

9. Basal-boundary stratotypes best defined at zonal/subzonal level

In 1964, another vital concept entered British geological thinking. In 1964, John Callomon published an important paper on the Callovian and Oxfordian stages [11]. In this, he pointed out:

– (a) that within the Mesozoic system, all its contained stages, substages, zones and subzones were successive subdivisions and that each was only of different rank from the others (i.e. all were hierarchical);

– (b) that the basis of all these units was palaeontological.

It followed that there could be two definitions of any one unit:

– (1) *typological*, as defined by a particular section at a type locality (those at stage level were the unit-stratotypes preferred in France), or

– (2) *hierarchical*, when any particular unit was defined in terms of those of next lower rank down to zonal/subzonal level.

Callomon stated his preference that stages should be only defined in terms of their constituent zones in a type area, not at any single locality and that this area should be left quite large. He pointed out that stages were simply not suitable; since if these "are to be the most general units for worldwide correlations, they are the units least likely to be sufficiently defined by any particular section at any one place". He showed that geologists needed to make hierarchical definitions more precise, down at their lowest level. He wrote "a faunal assemblage defining a zone has therefore itself to be defined by a type locality, which should now be quite closely specified" [11]. As Hancock has summarised, "stages are groupings of zones. Therefore, the concept of defining only the base of each unit should start at zonal level. [...] The base of each stage is defined by the base of its bottom zone. Type localities for zones were introduced by Callomon 1964" [24].

This principle of defining only basal-boundary stratotypes for only chronostratigraphic entities at this lowest hierarchical (zonal/subzonal) level has proved a significant advance, as I have noted [48]. At the same time, I questioned if this advance had indeed been due to Jurassic, as Ager claimed, or to Silurian specialists in Britain.

10. The invention of the basal-boundary stratotype concept

Before we attempt to answer this, we should first point out that "the concept of marker points is not, of course, a British invention". Sylvester-Bradley recorded that "he had become acquainted with it in 1961 during a session of the International Field Institute in Britain, held under the auspices of the American Geological Institute. I was leading a party of American geologists over the classic localities of the Jurassic System in England. Dr W.C. Bell, a member of the American Stratigraphic Commission, had brought with him a 'golden pick'. At each type locality, the pick was driven into the section at the base of the formation, and a photograph of it and the type section was taken" [45].

This was W. Charles Bell (1911–1979), of the University of Texas [23], but it is clear that his 'golden pick' was here being used only to define the bases of lithological formations. He never seems to have been used it in any attempt to define units of geological time.

Fig. 1. A Ludlow Research Group meeting at Ludford Corner, Ludlow, Shropshire, in 1982. Front row only (left to right): (1) Michael Bassett, (2) the late John Norton, (3) the late Helmut Alberti, (4) Dennis White, (5) the late Vic Walmsley, (6) Jim Lawson, (7) Charles Holland (photo courtesy of Dr Derek J. Siveter).

Fig. 1. Réunion du groupe de recherche de Ludlow à Ludford Corner, Ludlow, Shropshire, en 1982. De gauche à droite : (1) Michael Bassett, (2) John Norton (†), (3) Helmut Alberti (†), (4) Dennis White, (5) Vic Walmsley (†), (6) Jim Lawson, (7) Charles Holland (photo aimablement fournie par le Dr Derek J. Siveter).

Ager left a clue as to the first geologist to suggest the definition of chronostratigraphic units by ‘golden spikes’. In the second edition of his book, he had noted: “the one serious critic of my first edition told me that this was in fact proposed earlier by the ‘Ludlow Research Group’ [=LRG] for the Silurian” [4]. This LRG had been formed in 1952 with Dr James D. Lawson, then of the University of Birmingham as its first secretary [31]. His review of the first edition of Ager’s book, pointing out this earlier proposal, was published in 1974. It noted: “I object to the implication that the British Mesozoic Committee pioneered the principles of the ‘golden spike’ and of the definition of units by their bases. Professor Hedberg emphasised the need for definitions at standard sections about ten years earlier {in 1954, see [26]} and the principle was actually put into practice in Britain in the definition of the chronostratigraphical divisions of the Ludlovian in 1963 (the year before the British Mesozoic Committee ‘first introduced’ the principle) together with the principle of definition by the base of each division” [33].

Lawson was one of those who contributed to the 1963 paper he cited here [28] (Fig. 1).

In fact, Lawson alone himself had earlier made this suggestion and this should be put on record. In July/August 1960, Lawson had had a paper read for him on Stratigraphical Boundaries at a conference in Bonn, Germany, which was published in 1962 [32]. It noted “the interminable controversies which are revived with almost every new region that is studied, about the position of the boundaries between geological systems such as the Silurian and Devonian. The base of the Devonian must be defined and clearly marked at one particular standard exposure. Any strata elsewhere in the world which correlate with beds above this bedding plane but below the base of the Carboniferous shall be called Devonian; any strata above the base of the Silurian but below this marked bedding plane shall be called Silurian. The top of the underlying bed must not be defined as the top of the Silurian for if a break is later

Fig. 2. The first basal-boundary stratotype (GSSP) defining the base of the Ludlow Series and the Gorstian stage being sampled by Ken Dorning at Pitch Coppice, Wigmore Road, near Ludlow, Shropshire in 1991 (photo courtesy of Dr David J. Siveter).

Fig. 2. Première limite basale de stratotype (GSSP) définissant la base de la série de Ludlow et l'étage Gorstien, échantillonnée par Ken Dorning à Pitch Coppice, Wigmore Road, près de Ludlow, Shropshire, en 1991 (photo aimablement fournie par le Dr David J. Siveter).

proved the equivalent beds elsewhere will be neither Silurian nor Devonian" [33].

This is the clearest possible statement of both the problem (the potential overlap/underlap when using unit-stratotypes) and the solution (a single definition at the bases of units only). It is appropriate that it was this Silurian–Devonian boundary that was the first GSSP to be so agreed in 1972 [35].

This principle had been first put into practice in 1963, when the divisions of the Ludlovian Series at Ludlow were defined. Here, "the base of the Ludlovian Series is defined at a standard section and four stages are introduced. The boundaries between them are defined at standard sections" [28]. The base of the Ludlow Series, and now also of its constituent lower (Gorstian) stage was then defined at Pitch Coppice quarry, near Ludlow [5] (Fig. 2); a GSSP which still stands (but see below!).

In 1976, the first *International Stratigraphic Guide* devoted an entire chapter to stratotypes. It confusingly still demanded that stratotypes could comprise either unit-stratotypes or boundary-stratotypes, and it still urged that the practice of zoological nomenclature be followed, when urging greater stratigraphical 'precision' through the designation of potentially separate holo-, para-, lecto-, and neostratotypes. However, it did note the real problem with unit-stratotypes, that of "difficulties in time correlation which might leave gaps or overlaps" between stratotypes [27]. Nevertheless, in 1977, such guidance was simply ignored when the final decision, which had been taken in 1972, was published, to define the base of the Devonian, and thus the Silurian/Devonian boundary, by a basal boundary-stratotype at Klonk in the Czech Republic. This was after 1.5 decades of deliberation, so no one could accuse these of being anything but careful. The final defining character used at Klonk was the incoming within a single bed – itself a probable turbidite – of two defining subspecies of graptolite, i.e. 'merely' biostratigraphic characters. Twenty-three committee members voted for this, seven against and four abstained [35].

11. GSSPs are ratified

The latest revised guidelines (1996) of the International Commission on Stratigraphy (ICS) were "ratified

in a formal vote by the full commission. They stipulate that global chronostratigraphic units are NOT defined by unit-stratotypes, but by their lower boundary only, following the principle introduced with the definition of the base of the Devonian in 1972. This is indeed the only way to arrive at a global chronostratigraphic scale made up of strictly contiguous units" [39].

However, as we have seen, this principle had been first suggested over twelve years earlier by Lawson. As this 2000 *International Stratigraphic Chart* shows, an enormous effort has since gone into selecting and agreeing both officially accepted stage names and designating GSSPs for many of them. In this latest count, there are 31 GSSPs, of which 21 are Palaeozoic (in which the Silurian and Devonian are completely defined at stage level), while only two are Mesozoic and eight Cainozoic.

In 1997, the 'Comité français de stratigraphie' summarised current French views on stratigraphic terminology. It advocated that chronostratigraphic units might be defined by either unit-stratotypes or GSSPs. But it now considered that GSSPs were the best means by which definitions could be attempted, although it still regarded stages as the chronological units that should be defined [40]. Clearly, the lasting legacy of d'Orbigny was still being honoured.

12. New problems

In the last few decades, stratigraphy has moved from the field into the laboratory [48] and is now utilising an enormous range of 'new' stratigraphic skills, like cyclo-, chemo- and magneto-stratigraphy and/or sequence and/or event stratigraphy. Biostratigraphic data now longer rule. As a result, new frustrations are emerging over macrofossil-only based GSSPs, despite some passionate advocacy of their value [29]. In 1988, the French Bas Auran section was formally proposed as the basal-boundary stratotype for the basal zone/subzone of the Bathonian by a quartet of English, French and Italian geologists [30]. This outlined the ammonite distributions across that boundary in this section and also summarised the calcareous nannoplankton found there. This section was then thought to be 'ideal', since it showed:

– wonderfully preserved ammonite faunas;
– complete exposure;
– in a favourable facies;
– with no structural complications;
– a continuity of sedimentation with no physically (or biologically) discernable breaks;
– with good access and well conserved (it now falls within the 'Réserve géologique de haute Provence') [10], and;
– good cyclo-stratigraphic potential.

However, despite such apparent global potential not all demands for stratigraphic perfection could be met at this section. Neither radiometric dates nor magneto-stratigraphic data were available (as the section had been remagnetised to a steady normal polarity). A search for dinoflagellate cysts had also proved negative: "The only organic material in the samples was black coal particles, [because] during deep burial the organic material has been carbonised. [...] The section cannot, on this background, be recommended for the Bathonian stage basal boundary stratotype" [38].

Similar problems are now affecting the GSSP proposed for the overlying Callovian stage in 1990. This is another d'Orbignyan invention transposed from an English origin to French use. This had been the first Jurassic stage to have had its basal boundary typologically proposed at zonal level in 1964 [11]. This GSSP was to be in Germany in a new, freshly excavated section, near Stuttgart. This proposal drew the GSSP at the boundary between two specified ammonite horizons, the upper of which was here taken to mark the base of the basal zone of the Callovian. Eighteen members of the Callovian Working Group who then met at Stuttgart and at the section, accepted these "proposals as adopted as a whole and unanimously".

Nevertheless, objections were soon raised against this proposal and these have been lucidly discussed in a recent paper. The ICS Revised Guidelines of 1996 for the establishment of global chronostratigraphical standards were here reviewed one by one. Most were met fully. However, objections to this proposal were made on the grounds of supposed "geological requirements". At the heart of these objections was a perceived need for "continuous sedimentation: no gaps, no condensation in proximity of the boundary level" at such GSSPs. As Callomon and Dietl try to point out, such a wish-list is simply unattainable. There is no such thing as "continuous sedimentation" and any call for "no condensation" is "empty hand-waving, without quite detailed explanations of what is meant by 'condensation'". As these authors point out, "sedimentation can only appear to have been continuous and what matters is: how big must the gaps be before we detect them as sedimentary discontinuities?". The answer of course depends on the time-scale against which any completeness is being calculated. Such demands for completeness are at a level of precision far greater than any yet available in geology. As Callomon and Dietl concluded, "one does not buy a chronometer with millisecond time-resolution to check a phone-bill charged by the minute, or even a watch with a second-hand to time a hired car rented out by the day" [13].

The problem with both these two GSSP proposals is they are being rejected as 'less than perfect'. Each such GSSP proposal now has to be seen as more perfect than the previous. In two recent papers, Marie-Pierre Aubry, of Montpellier, has led a team of international stratigraphers who discussed similar problems manifest in Cainozoic stratotypes. She concluded that the essential problem lay in the available choice between two philosophies. Either "the stratigraphic community endorses the conceptual chronostratigraphic framework in which [...] the stage, with its unit-stratotype constitutes the fundamental stratigraphic unit in the chronostratigraphic hierarchy. [Here] definition precedes correlation. [...] Or the ICS maintains its current vision of the essence of chronostratigraphy. In this case, GSSPs are defined independently from unit-stratotypes [...] This second procedure has been followed by the ICS since 1986. It is clear that the two approaches cannot be reconciled, because there is no reason to expect that the base of chronostratigraphic units as defined in the first approach should be levels with the best potential for global correlation" [8].

In a later paper, she concludes that if we fail to agree between these two philosophies "chronostratigraphic units of long standing usage will be subject to redefinition each time a more powerful element of correlation is discovered", or, we might add, is claimed to have been discovered. "We view the concept of GSSP to be unsatisfactory and the procedures of the ICS to be dangerously simplistic" [9].

Sadly we may have to conclude that there may well be a third philosophy and that this additional one seems to have been the one tacitly accepted by many stratigraphers working in the Mesozoic who, as we have noted above, had, up to 2000, only bothered, or managed, to define two GSSPs across the whole time span of that long era.

John Callomon has recently pointed out how, "of the vast number of chronostratigraphical units in everyday use, the number so far formally defined in terms of typologically fixed bounding time planes is tiny" [12]. He concludes by noting that to get to the Geological Society of London (the publishers of this contribution), "you can usually tell whether you are in Piccadilly or not [where that Society is situated] without first having to find out were it formally starts and ends". His is part of a now widespread reaction against what some now see as over-imposed definitions. Otto Schindewolf, the German geologist, had early published a rebuttal of the whole philosophy of stratotypes, in 1970. He then wrote: "*ich vermag in dem hier geschilderten Aufwand der Stratotypen nichts anderes zu sehen als (sit venia verbo) ein Arbeitsbeschaffungs-Programm für reiselustige Stratigraphen*" [43].

Jim Lawson, the 'father' of the idea of basal-boundary stratotypes, wrote to me recently "how sad he was to discover even that the current Silurian Subcommittee is seriously considering proposals from members for the revision of some of the [already long ago defined] Silurian chronostratotypes, even though their physical condition has not deteriorated" [34]. This was confirmed to me by Barry Webby (see [48]). Under such circumstances, perhaps the future of the work of ICS in trying to define even more GSSPs/stratotypes will face being ignored by some of the best stratigraphers.

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