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International definition of Devonian System boundaries

MICHAEL R. HOUSE

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Since 1960 three committees of the International Union of Geological Sciences have been considering international definition of the base, top and subdivisions of the Devonian System. Agreement on these has either been achieved or is imminent. The committees have travelled to many countries and met a fascinating range of problems relating to international correlation and many personal, national and scientific considerations have been discussed. Extraordinary evidence of the diverse use of so-called standard subdivisions of the Devonian have been uncovered as a result of refined global correlation. A review is given of the new definitions and how these will apply to the rocks of south-west England, on the basis of which the Devonian System was founded in 1839.

Professor M.R. House, Department of Geology, The University of Southampton, Highfield, Southampton S09 5NH.

Introduction

International agreement on the use of terminology is essential for clear understanding, communication and interpetation in the Earth Sciences. From the first Congress of Geologists (later International Geological Congress or IGC) held in Paris in 1878 this was recognised as a major scientific need and committees were set up to achieve this for stratigraphic terminology. In Bologna in 1880 it was recommended that all systems should be divided into three divisions, and the Devonian is still divided into Lower, Middle and Upper Series.

Stage subdivisions have a more complex history and at the 1910 meeting of the IGC in Stockholm deference to the local definition in type areas led to the proposal by M.L. Wagen that there should be a *Lexique Stratigraphique Internationale* giving precise definition of local terms, and especially those that were by then being adopted internationally. By the London IGC in 1948, however, only one volume (Africa) had appeared. Subsequently, under the direction of Pierre Pruvost and others, many volumes appeared. These follow the precept that "Naturelement pour les termes stratigraphiques ayant leurs stratotypes dans the pays correspondant, un development plus large est a prevoir." Thus it was hoped that a standard would be established based on local type areas. Such was not to be.

With the increase in precision in methods of international biostratigraphic correlation and dating it gradually became appreciated that system, series and stages names were being used in quite different senses around the world. Even worse that substantial discrepancies existed in the very definition of the top and base of the Devonian. National interests were at stake, for maps had been produced and enormous literature had been linked to one or another contending usages. Different definitions were often used by different specialisms and specialists, and by different countries. Under the mask of an apparently common terminology, the reality was chaos. Something of the disparity of usage is illustrated in Fig. 1. One of the aims of the Commission on Stratigraphy of the International Union of Geological Sciences (IUGS) has been to establish committees to try and reach international agreement on definitions so that acceptance by the IGC could codify accepted standards. This paper recounts the attempts made for the Devonian System by the three committees on which the author has served as voting member: the Committee on the Silurian-Devonian Boundary, the Devonian Subcommission and the Working Party on the DevonianCarboniferous Boundary.

Major international divisions and criteria for their definition

Fortunately for the Devonian there has been no debate on whether Devonian is the appropriate name for the system. Some Americans hankered after the term Erian, but they never pressed the case. So there has been none of the hassle comparable with Silurian versus Gothlandien, or Mississippian/Pennsylvanian versus Carboniferous.

There has always been a general acceptance of three subdivisions for the Devonian, and of the Lower, Middle and Upper Series terminology, even if the meaning of the terms has differed.

The stage terminology has not been so simple (Fig. 2). The Lower Devonian stages, Gedinnian, Siegenian and Emsian of the Ardennes and Eifel have had wide use in western Europe and elsewhere for clastic sequences. But following the detailed description of the Czech sequences by Ivo Chlupáč, a terminology using Lochkovian, Pragian, Zlichovian, Dalejian for carbonate facies had been widely adopted in western North America, Asia and Australia. Correlation between the terminologies has been in dispute, and the definition of each is not without problems.

For the Middle Devonian, the stage names Eifelian and Givetian were used in Germany, but French speakers preferred Couvinien

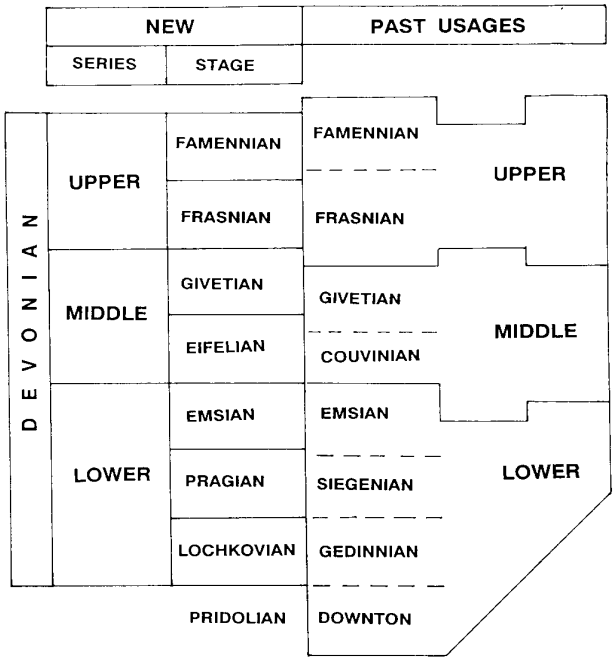

Figure 1. Diagram illustrating the new stage and series terminology for the Devonian contrasted with past usages which differ widely from country to country and author to author.

and Givetien. The definition of each differed significantly. The Upper Devonian was generally agreed to be divided into the Frasnian and Famennian but the diverse definitions of the top of the system, meant that the late Famennian, especially for French speaking geologists, was named the Strunian and referred to the Carboniferous.

The role of priority

In zoological nomenclature the rules of priority have generally served to stabilise taxonomic terminology. Why, it may be asked, does not this hold for stratigraphic terminology? The simplest answer is that intrenched viewpoints are too strong; that when terms were originally applied knowledge was in reality only local and vague; and that the international consensus view is that a compromise should now be agreed to give boundaries of maximum usefulness and which enable global correlation as far as possible.

For the base of the Devonian Murchison did in fact define a top for the Silurian in the Welsh borderlands and for the top of the Devonian Sedgwick and Murchison did give a stratotype at Fremington Pill, North Devon. As will be seen below, international decisions were taken to choose other levels and other localities to define these boundaries anew. In many ways this was unfortunate because there is now no role for priority, no focus on a type area and, once change has been decided it becomes easier for a subsequent generation to introduce change again. As was said, "will the traditional view that boundaries are defined by the accepted usage in the place of origin of the term be abandoned until the whole panoply and splendour of an international committee can deliberate and decide on everything?" (House 1978).

Faunal definition

There has been a view that since any boundary could only be correlated by fossils it is only necessary to decide on a zonal boundary and no specification of type locality is necessary. This was expressed especially by Professor O.H. Walliser (McLaren 1977, p. 12) who dissented from the decision on the SiluroDevonian boundary taken in 1968. This view was not accepted by the majority because incorrect and subjective faunal and floral correlation was the cause of much of the problem. A boundary stratotype defines a boundary in space and time using fossils. But once the decision is taken it is the *boundary stratotype* and *not* the fossils which defines the boundary. The wisdom of the majority view is shown by the growing development of other means of correlation using magnetostratigraphy, ash bands, Milankovitch rhythmicity, and using new studies of different fossils since these can be accommodated once a boundary stratotype is decided.

Global events

In the Devonian it has been increasingly claimed that there are certain levels where sedimentary perturbations can be recognised internationally. The late Frasnian Kellwasser Limestone (or Kellwasser Event) is such and some think this may represent the effects of a bolide impact, or cosmic showers (McLaren 1970, 1982). Other levels have been documented (Walliser 1984: House 1985). There has been a groundcurrent view that if these do represent single ‘bioevents’, or catastrophic events, then they should be used to define stage or series boundaries if at all possible. The reality is more complex. The Frasnian/Famennian boundary, if taken at the base of the Lower *triangularis* Zone, as recommended by Sandberg and Ziegler, gives rise to problems in the selection of good boundary stratotype because it lies within the perturbations of the Kellwasser Event. Similarly the Devonian/Carboniferous boundary at the base of the *sulcatus* Zone lies within perturbations of the Hangenberg Event. The problems are compounded by the fact that there is no agreement on the cause of the perturbations. Clearly the recommendation to draw a boundary level in such bands was not wise.

Golden spikes

The various committees of the Subcommission on Stratigraphy thus conform to the recommendation that critical boundaries are defined at a single horizon in a single section named the boundary stratotype section. The point represented by the theoretical `golden spike' thus defines the boundary in space and time. In some cases the boundary stratotype has been ratified and accepted. In other cases the faunal level has been decided and proposals are awaited on candidate boundary stratotypes. Nevertheless the formal subdivisions of the Devonian are now established which will be used as an international standard. The implications for south-west England are discussed in that light.

Silurian/Devonian Boundary

The boundary stratotype for the Silurian/Devonian (and Pridolian/Lochkovian) boundary is at Klonk, 35km south-west of Prague. Here the boundary is drawn within Bed 20 where the graptolite zonal index *Monograptus uniformis* enters: a trilobite guide-fossil, *Warburgella rugulosa rugulosa* enters shortly above. The conodont guide *Icriodus woschmidti* enters a little earlier in other sections (Martinsson 1977; Chlupáč et al. 1972). This level appears to correspond to a level a little below the Psammosteus Limestone of Shropshire, Monmouth and Herefordshire in the Welsh Borders. The level has not been identified clearly in southwest England but Sadler (1973) recognised *I. woschmidti* in the Roseland area of South Cornwall and the cruder guide to the late Silurian, *Scyphocrinites*, has long been known there. Dineley (1986) reports traquairaspids in South Devon that suggest Lochkovian (Gedinnian) is present so that the Dartmouth Slates include very early Lower Devonian (Fig. 2).

This boundary illustrates well the problems of relying on extinctions to define faunal boundaries. In Britain there had been considerable diversity on which level was to be taken as the base of the Devonian, from levels as low as those recommended by Murchison near the Ludlow Bone Bed to levels at the top of the Downtonian (just below the Psammosteus Limestone) where graptolites are last seen (White 1950). In many other parts of the world the extinction of graptolites was taken to mark the close of the Devonian. Then many discoveries disproved this, especially the recognition by Hermann Jaeger that *Monograptus hercynicus* was associated with Siegenian brachiopods in Thuringia. Now it is known that graptolites range up probably to the Emsian in appropriate facies and that the early disappearance from Britain is due to local facies changes.

A Committee on the Silurian-Devonian Boundary and Lower and Middle Devonian Stratigraphy was established at the 1980 IGC meeting in Copenhagen following recommendations from the 1960 Bonn/Brussels meetings (Erben 1962), itself preceded by a meeting in Prague in 1958 (Svoboda 1960). Professor H.K. Erben and from 1968 Dr D.J. McLaren acted as chairmen. Subsequently meetings were held, either of the committee or related groups and usually with associated publications, at Rennes (1964), Calgary (1967) (Oswald 1967) Leningrad/Siberia/Ukraine (1968), Prague (1968), Nevada (1970), Prague (Barrandian) (1970), Morocco (1971) and final recommendations were approved by the IGC at Montreal (1972). All this has been documented by McLaren and others (in Martinsson 1977), and the type area for the underlying late Silurian has been described (Kriz et al. 1986). Thus the final decision was a result of much international co-operation. Study of this boundary level has continued as *Project Ecostratigraphy*.

Boundaries within the Devonian

Decisions on boundaries within the Devonian will be considered in stratigraphical order using stage boundaries as the key (Fig. 2) but this differs from the order in which they were discussed. Recommendations here have been the responsibility of the Subcommission on Devonian Stratigraphy which was established by IUGS in 1972 and which has worked under the successive chairmanship of Prof. H.K. Erben, Prof. W. Ziegler and Dr. W.A. Oliver, Jr. Meetings of the Subcommission, or meetings of related groups, have been held in Marburg (1973),

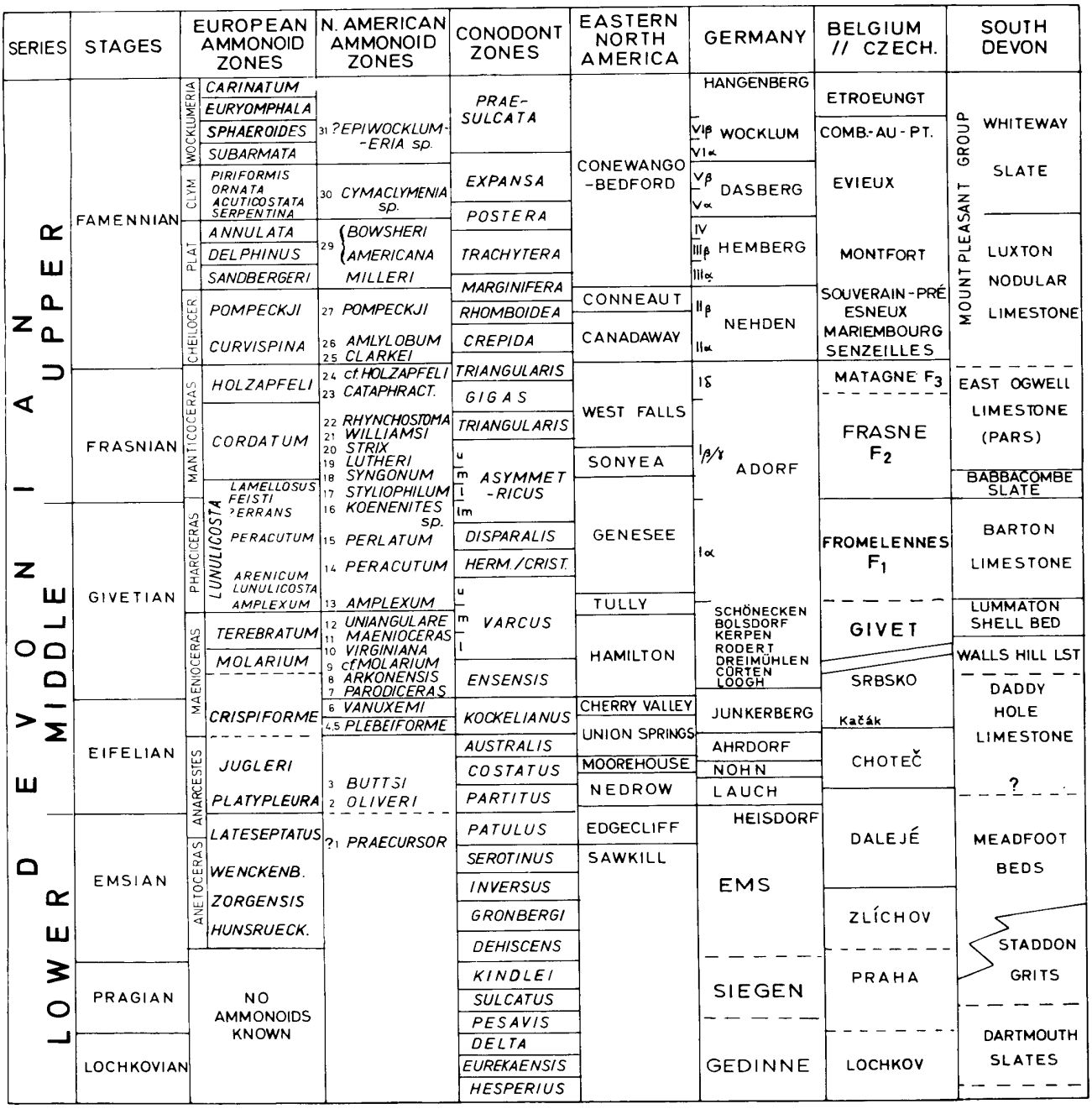

Figure 2. Table showing the relation of the newly defined divisions of the Devonian to standard biostratigraphic scales and to lithostratigraphic sequences of several parts of the world including Devon

Eifel/Ardennes (1974), Morocco (1975), Australia (1976), Czechoslovakia and Germany (1977), Samarkand and Tien Shan Mountains (1978) (Sokolov and Rhonsnitskaya 1982), Bristol (1978) (House et al. 1979), China (1979), Spain/Brittany (1979), Paris (1980), New York State (1981), Ardennes and Rhenish Mountains (1982) (Ziegler and Werner 1982), Montpellier (1983) (Lardeux 1983), Bristol (1985) (Ziegler and Werner 1985), Prague (1986), Calgary (1987), Spain/Brittany (1988) and final recommendations are hoped to be presented at the IGC meeting in Washington (1989).

It has been agreed that the stage names adopted for the Lower Devonian should be as indicated in Fig. 2. The two old terms Gedinnian and Siegenian correlate very approximately with the Lochkovian and Pragian stages which are much better defined in terms of conodonts, tentaculitids and brachiopods.

Base of Pragian

At Calgary (1987) it was decided that this boundary be selected within the band or interval marked by the first appearance of the conodont *Eognathodus sulcatus* and the tentaculite *Nowakia arcuaria* which was said to enter a little higher. This level is slightly below the base of the Praha as defined as present (Fig. 2)

but which would be redefined. Levels as high as the base of the *gronbergi* Zone and as low as within the *pesavis* Zone were considered. The boundary faunas were analysed by Weddige (1987) for the Prague area who recommended using the entry of E. sulcatus. A boundary stratotype has still to be decided. In Devon this boundary is probably within the Dartmouth Slates but, until some good correlation with non-marine facies is established, it is unlikely to be recognised with precision.

Base of Emsian

The level agreed at Calgary (1987) is a band within the range of overlap of *pireneae* and *Polygnathus dehiscens*. A boundary stratotype has still to be decided and a final exact level chosen. Nevertheless the band selected is near the base of the dehiscens Zone (Fig. 2) and represents a level which may be widely recognised internationally. In south-west England the level will lie. at a horizon within the Staddon and Meadfoot Beds.

The term Emsian, based on the type Ems Quartzite (Kutscher and Schmidt 1958), has come to replace Coblenzien relatively recently. Major difficulties here have been related to problems in correlating the clastic type sections with carbonate sequences elsewhere in which conodonts, brachiopods and goniatites are more common. During initial discussions it was thought likely that Zlichovian and Dalejian might have replaced Emsian for international acceptance, and they may still survive as substages. The solution of the correlation problem has been indirect, taking advantage of Spanish and other sections which carry both elastic and carbonate faunas (Carls 1987). It is likely that the new definition will include in the Pragian most levels with *Acrospirifer primaevus*, *Arduspirifer arduennensis* and *Hysterolites hystericus* and in the early Emsian levels with *Acrospirifer fallax*, and *Arduspirifer antecedens* in the early Emsian but conodont faunas will be critical for the recognition of the boundary. Goniatites, especially Anetoceras and other genera seem to enter in the late *dehiscens* Zone. Convenient faunal breaks for different groups lie at different levels and the consensus is likely to favour the boundary level which is most readily recognisable internationally. It is hoped that at the Rennes meeting (1988) progress will be made towards this.

Base of Eifelian (and Lower/Middle Devonian Series Boundary)

In 1979 the Subcommission voted for a level to define the Lower/Middle Devonian boundary at the lower boundary of the partitus Zone. In 1981 the Subcommission selected a boundary stratotype marked by the base of Bed 30 in the Wetteldorf Richtschnitt in the Eifel Hills of West Germany (Ziegler and Werner 1982, pp. 13-84) and a parastratotype level was chosen in the Holyne Prastav Quarry southwest of Prague (Chlupáč in Zielger and Werner 1982, p. 85-96). The exact level of this boundary in the sequences of south-west England remains to be determined since detailed conodont work has not been done over the critical boundaries in South Devon. Nevertheless it seems that it will closely correspond to the Meadfoot Beds/Daddy Hole Limestone boundary.

Problems here relate to whether Couvinien or Eifelian should be used for this stage and whether the boundary should be close to the base of the former or the latter. In Belgium and Schiste de Bure á *Paraspirifer cultrijugatus* was placed in the Middle Devonian. In Germany the Lower/Middle Devonian boundary was drawn at the Heisdorf/Lauch boundary in the Eifel Hills. Nationalistic and linguistic preferences dominated the early discussion.

International consideration of this boundary commenced at the 1958 Prague meeting (Svoboda 1960) and 1960 Bonn meeting (Erben 1962) before the establishment of the Subcommission. It formed a substantial item for debate at other meetings, particularly a meeting in the Eifel and Ardennes in 1974. Great progress was made towards conclusion at the 1978 Samarkand meeting (Sokolov and Rzhonsnitsaya 1982).

Base of Glvetian

At Calgary (1987) it was agreed that an interval from the base of the ensensis Zone to the base of the varcus Zone and not excluding the base of the *obliquimarginatus* Zone (Ziegler 1971) which was replaced by the ensensis Zone by Weddige (1977) should be the band for definition of the level for this boundary. The exact level and stratotype remain to be determined. This time band will probably fall within the Daddy Hole Limestone since the top of this unit is marked by 10m of dark limestone at the base of the sea cliffs at the northern end of Redgate Beach (SX 93576497) which is referred to the upper *ensensis* Zone (Austin et al. 1985, p. 108) to within the Walls Hill Limestone. The level outside South Devon is uncertain.

Many levels were discussed before reaching the present consensus. The band decided is much higher than that represented by the international occurrence of the goniatite *Cabrieroceras crispiforme* which is found, for example, in the upper Union Springs in New York or the Kacak member in Czechoslovakia (Fig. 2), a level sometimes called the Otomarii Event which had been used to define this level on the goniatite scale. Goniatites are generally very poorly known in this part of the Devonian and the *molarium* Zone, at its type locality at Wolborough, is thought to be within the varcus Zone (Selwood et al. 1984, p. 174) and presumably the early part of that zone.

Base of Frasnian (and Middle/Upper Devonian Series Boundary)

The decision has been made to define the base of the Frasnian stage and base of the Upper Devonian within bed 42a at the boundary stratotype section at Col du Puech de la Suque, near St Nazaire de Ladarez in the Montagne Noire, southern France (Klapper et al 1987). The level is the base of the Lower asymmetricus Zone in the conodont zonation. In Devon this level is within the succession in Barton Quarry (SX91256710), Torquay (Austin et al. 1985, p. 130). It was this quarry which yielded the corals which led William Lonsdale to propose the founding of the Devonian System. On the South Devon coast the level is probably represented by the base of the Babbacombe Slate near Half Tide Rock (House 1964; Castle 1982). The level is present on the north Cornwall coast where it is at the base of Bed 151 in the excellent sequence of the Marble Cliff Beds (SW 891765) near Trevone, North Cornwall (Austin et al. 1985, p. 112, section also illustrated by House and Dineley 1985, p. 302).

In the major review of the Devonian system resulting from the Calgary meeting of 1967 (Oswald 1968) there was almost unanimous use of a base for the Upper Devonian at a level corresponding to the base of the Assise de Fromelennes (F1) in southern Belgium and northern France, the base of the *Manticocera*s Stufe and *lunulicosta* Zone, and the base of the Tully in New York (Fig. 2). In the succeeding twenty years this unanimity has been lost. The new boundary reflects a chain of incidental mis-correlations leading to the acceptance of a quite different level. The history of this boundary has been recounted in detail elsewhere (House 1973, 1982) and need not be repeated here. The salutary lesson is the ease with which long-standing boundaries and, in this case, boundaries which have resulted from IUGS committees, can be discarded. So too can any respect for priority. It must be recognised that once such action is allowed, it becomes much easier for it to happen again, and the result is destabilising.

Base of Famennian

Decisions were made at the 1987 Calgary meeting to revoke an earlier decision (made at Montpellier in 1983) that the boundary level should be the base of the Middle *triangularis* Zone in favour of a level at the base of the Lower *triangularis* Zone. A decision was made by those present that the stratotype should be a section in the Montagne Noire above the Coumiac Quarry (Feist 1983; Feist and Flajs 1987). This will require reconsideration since sedimentary perturbations seem internationally associated with the level chosen which correspond to later parts of the Kellwasser Event. Aspects of the history of this boundary have been

reviewed elsewhere (House 1973). So far as south-west England is concerned the precision of knowledge is not such as to help. The entry of *Cheiloceras*, which has been used in the past, is a little above any of the contending levels. But it seems that Kiln Wood (SX85086942), Chudleigh, exposes the best sequence across the boundary (Tucker and van Straaten 1970; House and Butcher 1973).

Devonian/Carboniferous Boundary

This boundary is now taken at the level of the base of the conodont *sulcata* Zone. A final recommendation will depend on decisions taken in May 1988 probably from among boundary stratotype proposals at Hasselbachtal (Germany), Drewer (Germany), Montagne Noire (France), Muhua (China) and Dapoushang (China). This boundary is only fractionally below the former level at the base of the *Gattendorfia subinvoluta* Zone level. This boundary has been generally followed in the British Isles (House et al. 1979) so little change is required. The former *Wocklumeria/Gattendorfia* boundary was recognised in North Devon, but the best sequence showing the new boundary was described from boreholes at Chillaton by Selwood et al. (1982).

At Heerlen in 1935 the Carboniferous Congress decided to take the base of the Carboniferous at the entry of *Gattendorfia* subinvoluta and the base of the Gattendorfia Genus Zone (or Stufe) using the reference section at the Oberrödinghausen railway cutting in the Sauerland (Jongmans and Gothan 1937, p. 6). This boundary was followed in most countries, but French speaking countries, and the USSR, continued to use a lower boundary at the base of the Strunian, near the base of the Wocklumeria Genus Zone. So international agreement was not achieved by the Heerlen decision. Furthermore, increased use of conodonts and spores led to pressure for a redefinition in terms of groups more widespread than goniatites.

The IUGS Working Party on the Devonian-Carboniferous Boundary was organized in 1976 following discussions in Krefeld (1971) and in Moscow (1975). The first meetings were held at Bristol and Cork (1978) (Paproth 1978). At Washington and Urbana (1979) a decision was made to recommend an operational boundary using the entry of *Siphonodella sulcata*, a level a little below the entry of *Gattendorfia subinvoluta* (Paproth 1980). The search for a stratotype commenced. Other meetings were at Leeds (1981), the Rhenish Slate Mountains (1982) and Moscow (1983). By the Madrid meeting (1983) stratotypes were under consideration at Hasselbach (Germany) (Becker et al. 1984), Kija (subsequently withdrawn) and Berchogur (USSR) (later withdrawn) (Barskov et al. 1984) and Muhua (China) (Hou et al. 1984, 1985). By then it was appreciated that the new boundary level was recognisable by the entry of imitoceratid goniatites with open-umbilicate early stages referred for convenience but inappropriately to the genus *Acutimitoceras* (Price and House 1984). At Montpellier (1987) difficulties in finding a good stratotype were increasingly appreciated and for the meetings in Cork (1988) only four are under consideration, Hasselbach (Becker 1988), Drewer (Clausen et al. 1987), Montagne Noire (Feist and Flajs 1987), and Guilian (Yu et al. 1987). It is hoped that recommendations from that meeting can be ratified for presentation to the IGC in Washington, 1989.

Conclusions

International efforts to achieve consensus on the use of stratigraphical terms for the Devonian have resulted in spectacular increases in knowledge and the recognition of many errors in past interpretation. The precision with which boundaries can now be recognised, given appropriate faunal or floral representation, must be approaching the resolution possible with such methods.

However, most work has been done on the correlation of marine strata and the whole matter of non-marine strata has hardly been touched. Because conodonts have been most useful for fine resolution, microfossils have tended to control decisions, but for field geologists, macrofossils are often more helpful in enabling immediate recognition of time levels whilst in the field. Many previously valuable markers using macrofossils have now gone. In general it is to be regretted that priority has generally been ignored: this is because a reasonable aim has been to accord with current international usage as far as possible. This means that none of the boundaries recommended is sacrosanct even when they have JUGS approval. Approved IGC boundaries have been discarded in the past and can be again. Nevertheless the result of this effort of many geologists has been to establish the Devonian as one of the best classified systems and one where substantially international agreement has been reached on all its constituent subdivisions. This is a major achievement.

More importantly the way is now open for the analysis of the real geological problems of the Devonian within the framework of an agreed terminology and very refined correlation. Considerable advances are now to be expected in palaeogeographic and palaeotectonic reconstructions, in studies of sea-level changes and of palaeoecological fluctuations through time. A more critical study of evolutionary changes and the nature of the anoxic `events' and other perturbations in the record of the Devonian is now possible. This will be the genuinely *scientific* outcome of the work of the three JUGS subcommittees.

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Note added in proof

At a meeting of the Working Party on the DevonianCarboniferous Boundary held in May 1988 a decision was taken to recommend as Global Boundary Stratotype for the DevonianCarboniferous boundary the section at La Serre in the Montagne Noire described by Flajs and Feist (1988) with the Global Boundary Stratotype Point at the base of their bed 89. Other information is contained in Flajs et al. (1988). This was coupled as a package with the recommendation that two other sections should be regarded as Auxilliary Stratotype Sections, namely Hasselbachtal (Becker et al. 1984; Becker 1988) and Nanbiancun (Yu Chang-Min 1988). The matter was referred to a postal vote when it received a 70% majority vote and the recommendation is now being forwarded to the International Commission on Stratigraphy.

A meeting of the Devonian Subcommission was held at Rennes in August 1988. The base of the Pragian was recommended at the entry of *Eognathus sulcatus* in the Velka Chuchle, near Prague. This is now subject to postal voting. Stratotype sections are being sought for the base of the Emsian within the overlap of *Polygnathus pyreneae* and *P. dehiscens*. For the base of the Givetian it was agreed that attention should be paid to the first occurrence of *Polygnathus hemiansatus* as a guide to this boundary and a stratotype decision would be delayed. On the base of the Famennian the Subcommission reconfirmed its preference for the base of the Lower *triangularis* Zone to define this: of the several stratotype proposals before it the attending members preferred the E 1 Atrous section in southern Morocco and a further year was allowed to permit more documentation of this to be presented.

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