The Upper Jurassic of Europe: its subdivision and correlation

Arnold Zeiss

In the last 40 years, the stratigraphy of the Upper Jurassic of Europe has received much attention and considerable revision; much of the impetus behind this endeavour has stemmed from the work of the International Subcommission on Jurassic Stratigraphy.

The Upper Jurassic Series consists of three stages, the Oxfordian, Kimmeridgian and Tithonian which are further subdivided into substages, zones and subzones, primarily on the basis of ammonites. Regional variations between the Mediterranean, Submediterranean and Subboreal provinces are discussed and correlation possibilities indicated. The durations of the Oxfordian, Kimmeridgian and Tithonian Stages are reported to have been 5.3, 3.4 and 6.5 Ma, respectively.

This review of the present status of Upper Jurassic stratigraphy aids identification of a number of problems of subdivision and definition of Upper Jurassic stages; in particular these include correlation of the base of the Kimmeridgian and the top of the Tithonian between Submediterranean and Subboreal Europe. Although still primarily based on ammonite stratigraphy, subdivision of the Upper Jurassic is increasingly being refined by the incorporation of other fossil groups; these include both megafossils, such as aptychi, belemnites, bivalves, gastropods, brachiopods, echinoderms, corals, sponges and vertebrates, and microfossils such as foraminifera, radiolaria, ciliata, ostracodes, dinoflagellates, calcareous nannofossils, charophyaceae, dasycladaceae, spores and pollen. Important future developments will depend on the detailed integration of these disparate biostratigraphic data and their precise combination with the abundant new data from sequence stratigraphy, utilising the high degree of stratigraphic resolution offered by certain groups of fossils. This article also contains some notes on the recent results of magnetostratigraphy and sequence chronostratigraphy.

Keywords: Europe, Upper Jurassic, Oxfordian, Kimmeridgian, Tithonian, Volgian, ammonite zonal and subzonal biostratigraphy and correlations, subdivision by non-ammonite fossil groups, chronometric data, magnetostratigraphy, sequence stratigraphy

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Contents

The term 'Upper Jurassic' ('Oberer Jura') was introduced by von Buch (1839). Arkell (1956) revived this name with only minor changes in its chronostratigraphic content. The term 'Upper Jurassic' in the sense of Arkell (1956) was accepted by the First and Second 'Colloque du Jurassique' at Luxembourg in 1962 and 1967; only the stage name 'Purbeckian' was eliminated, as it was considered to characterise merely a distinct lithofacies. This usage was followed by the five subsequent International Symposia on Jurassic Stratigraphy at Erlangen in 1984, Lisbon in 1987, Poitiers in 1991, Mendoza in 1994 and Vancouver in 1998. Focus on the formal stratigraphic subdivision of the Jurassic, and the Upper Jurassic in particular, is reflected in the series of key meetings since the early 1960's (Table 1).

The term 'Malm' was included in the recommendations of the First Luxembourg Colloquium in 1962 as an alternative term for the 'Upper Jurassic' (Maubeuge 1964). Although this term, like the term 'Tithonian' (see below), is not based on a geographical site, it has been widely used since its introduction by Oppel (1858, 1865). Referring to the Tithonian stage, Arkell (1956, p. 8) wrote: "it is too late to abolish it after a hundred years of continuous use"; this also applies to the term 'Malm'. It is important to note that both 'Upper Jurassic' and 'Malm' are chronostratigraphic terms; the latter, in particular, has frequently been used in a lithostratigraphic sense by some authors.

At the First Colloquium in Luxembourg in 1962, a subdivision of the Jurassic System into stages was proposed, the basic framework of which has survived to the present day. The stages were defined by their lower and upper ammonite zones. The recommendations of the First Colloquium (Maubeuge 1964) were thus a landmark in the history of international agreements concerning the subdivision of the Jurassic System into series and stages.

After a period of discussion following the publication of the resolutions of the Luxembourg Colloquia (Maubeuge 1964, 1970), these proposals have been accepted

Table 1. Key events in Upper Jurassic stratigraphy since 1960

Date	Place	Event	Reference
1962	Luxembourg	Colloque du Jurassique à Luxembourg	Maubeuge 1964
1965	Sofia	VII Congress, Carpatho-Balkan Geological Association	CBGA 1965
1967	Luxembourg	Colloque du Jurassique à Luxembourg	Maubeuge 1970; BRGM 1974
1967	Moscow	International Symposium on Upper Jurassic stratigraphy	ANSSR 1974
1969	London	William Smith Symposium on Jurassic geology	
1969	Budapest	Colloque du Jurassique Méditerranéen	Végh-Neubrandt 1971
1973	Neuchâtel	Colloque sur la limite Jurassique–Cretacé, Lyon	BRGM 1975
1975	Sofia	International Symposium on the Jurassic–Cretaceous boundary in Bulgaria	Nikolov & Sapunov 1977
1977	Stuttgart	International Field Meeting on the Jurassic System of southern Germany – this meeting initiated the reorganisation of the International Subcommission on Jurassic Stratigraphy	Zeiss 1977; Ziegler 1977
1979	Novosibirsk	International Colloquium on the Upper Jurassic and the Jurassic–Cretaceous boundary	Saks 1979
1984	Erlangen	International Symposium on Jurassic stratigraphy	Michelsen & Zeiss 1984
1984	Sümeg	Meeting of the Working Group for the Jurassic–Cretaceous boundary	Fülöp 1986
1987	Lisbon	2nd International Symposium on Jurassic stratigraphy	Rocha & Soares 1988
1987		International Field Meeting on Jurassic–Cretaceous boundary problems at the Northern Caucasus	Menner 1990
1988	Zaragoza	1st Oxfordian Working Group Meeting, Zaragoza – Iberian Chain	Meléndez 1990
1990	Basel	2nd Oxfordian Working Group Meeting, Basel and Jura range of northern Switzerland	Gygi 1990b
1991	Poitiers	3rd International Symposium of Jurassic stratigraphy	Cariou & Hantzpergue 1994
1992	Warsaw	Joint Meeting of the Oxfordian and Kimmeridgian Working Groups	Atrops *et al.* 1993a
1993	London	W. J. Arkell Symposium of Jurassic geology	Taylor 1996
1994	Mendoza	4th International Symposium on Jurassic stratigraphy	Riccardi 1996
1994	Lyon	4th Oxfordian and Kimmeridgian Working Groups Meeting, Lyon and South-Eastern France Basin	Atrops & Meléndez 1994a
1997	Warsaw	Oxfordian (Jurassic) Meeting in Poland	Glowniak *et al.* 1997
1998	Vancouver	5th International Symposium on the Jurassic System	Pálfy 1998, Hall & Smith 2000

worldwide, the only exception being that in the former Soviet Union the Callovian has been considered to belong to the Upper Jurassic (see Krymholts *et al.* 1988), while in the rest of the world the Callovian is included in the Middle Jurassic. However, following a decision by the Interdepartmental Stratigraphic Commitee in 1989, the Callovian is also now considered in Russia to belong to the Middle Jurassic (Zhamojda 1991).

According to the most recent estimates, the Late Jurassic had a duration of a little more than 15 million years according to Gradstein *et al.* (1994, 1995; Ogg 1995), or 12 million years (+5.6/-7.3) according to Pálfy *et al.* (1998). The data of Gradstein *et al.* (1995) have been used in Figures 2, 4 and 5 of this paper; on this basis each of the three Upper Jurassic stages has an average length of 5 million years, while zones and subzones have approximate durations of 700 000 and 300 000 years, respectively. Each subzone comprises at least three horizons, each of which has an approximate duration of 100 000 years.

Subdivision and definition of stages: status and unsolved problems

On the basis of the recommendations of the First Luxembourg Colloquium (Maubeuge 1964), the Upper Jurassic Series was subdivided into four stages for the Boreal and Subboreal regions: Oxfordian, Kimmeridgian (*sensu anglico*), Portlandian (*sensu anglico*) and Volgian, and three for the Submediterranean and Mediterranean regions: Oxfordian, Kimmeridgian (*sensu gallico* equivalent to 'Crussolian') and Tithonian (equivalent to 'Danubian' and 'Ardescian'). In the following decades, there has been much confusion as the Kimmeridgian and Portlandian Stages have often been used differently in different parts of Europe.

In 1990, a formal vote of the International Subcommission on Jurassic Stratigraphy (ISJS) led to the decision to use stages with approximately the same vertical age ranges and uniform names in both regions: Kimmeridgian (*sensu gallico*) and Tithonian (Zeiss 1991a). With regard to the still unresolved correlation problems between the Boreal and Mediterranean provinces, it was agreed that the Volgian can be used as an alternative stage for the Tithonian in Subboreal and Boreal regions (Fig. 1).

The main problem which remained to be solved was the definition of the lower boundary of each stage. To date, no stage has a type locality and a defined lower boundary (global stratotype section and point, or GSSP) formally accepted by the International Commission on Stratigraphy (ICS). There are of course a lot of proposals, but they have not been validated according to the guidelines and rules of the ICS (Cowie *et al.* 1986; Remane *et al.* 1996).

The most intractable problems are to find isochronous levels in Submediterranean (and Mediterranean) and Subboreal (and Boreal) Europe for the lower boundary of the Kimmeridgian Stage and for the upper boundary of the Tithonian (Volgian) Stage. As the former is of particular significance for Upper Jurassic subdivision and correlation, it will be treated here in some detail (see below).

Other problems are the unification of the differing subdivisions of stages into substages, correlation of the zones of each stage between the different areas of Europe and the development of better correlation charts from the Boreal regions to the Mediterranean areas. Provisional correlation charts on a zonal and subzonal level for each stage of the European Upper Jurassic are presented here (see Figs 2–5). Zones and subzones are used here as chronozones following the International Stratigraphic Guide (Salvador 1994); originally, many of them were defined as biozones whereas others were used as standard zones, standard chronozones or biochronological standard zones, i.e. only the base is defined while the top is defined by the base of the next overlying unit (Callomon 1965, 1984a, 1994). Problems arise, however, due to inconsistent usage of the term 'standard zone'. In Northwest Europe, standard zones are mostly used following the concept of Callomon (1994), whereas in central and southern Europe, standard zones are often synonymous with biostratigraphic zones for use in biochronology (Cariou & Hantzperque 1997). It is often difficult, therefore, to determine in which meaning 'standard zones' are used. The problems encountered in moving from biostratigraphic field data to biochronological interpretations have been discussed recently by Remane (1991).

The term biochronological zone is now used by many authors instead of chronostratigraphic zone, if the zone is based on fossil data. As the ultimate subdivision of biochronology, French authors use the term 'biohorizon' (e.g. Enay 1997); their concept is therefore 'sensiblement different' from the pure biostratigraphic horizon concept of J.H. Callomon (Dommergues 1997).

No attempt has been made here to correlate ammonite faunal horizons due to the variable nature of the published research on the Upper Jurassic in the various sedimentary basins of Europe. Where necessary, however, correlations of horizons are discussed in the text.

For an example of such horizon correlations, the reader is referred to the work of Callomon (1984c) on the Upper Jurassic of North America (this study also covers the European *Amoeboceras* subdivision). Although attempts have been made to generalise horizons for the whole 'domaine tethysien' and 'domaine boréal' (Cariou *et al.* 1997; Hantzperque *et al.* 1997), these appear premature and of little practical use, given the present state of knowledge.

In Europe, subdivisions down to the level of ammonite faunal horizons have been proposed for several sedimentary basins. Such studies include that of the Upper Jurassic of East Greenland by Callomon & Birkelund (1980, 1982; Birkelund & Callomon 1985), the Lower Kimmeridgian of southern England by Birkelund *et al.* (1983), the Kimmeridgian of Spitsbergen by Wierzbowski (1989), the Kimmeridgian of the Barents Sea by Wierzbowski & Smelror (1993), the lowermost Oxfordian of northern France by Vidier *et al.* (1993), the Upper Oxfordian, Kimmeridgian and Lower Tithonian of western France by Hantzperque (1989), the lowermost Oxfordian of south-east France by Fortwengler & Marchand (1994b), the Lower Kimmeridgian of south-east France by Atrops (1982), the Upper Oxfordian, Upper Kimmeridgian and Lower Tithonian of south-west Germany by Schweigert (1994, 1995a, b, 1996a, b; Schweigert & Callomon 1997), the Oxfordian–Kimmeridgian of Poland (Matyja & Wierzbowski 1997), the Middle Volgian of central Poland (Kutek 1994) and the Oxfordian of north-east Spain by Cariou *et al.* (1991a) and Meléndez & Fontana (1993).

The 'faunal horizon' approach clearly represents a method for increasing precision in correlation and dating in the future, when the data from the various sedimentary basins reach the necessary standard. It is already proving useful in deciphering the history of basin deposits at a resolution that was hitherto impossible; such data, in particular, allow us to date events more precisely and to determine the 'completeness' of the sedimentary record i.e. to identify accurately the position and duration of hiatuses. A prerequisite is, however, that it is possible to reconstruct the complete succession of faunal horizons by correlating individual local successions.

In this context, it is worth mentioning that the methods of Jurassic stratigraphy and high-resolution geochronology have been discussed in detail by Callomon (1984a, b, 1994, 1995), Page (1995), Corna *et al.* (1997), Blau (1998) and Blau & Meister (2000); formal aspects were covered by Remane (1996).

The Upper Jurassic (Malm) Series (Fig. 1)

In this paper, subdivision and correlation of the Upper Jurassic Series have been carried out mainly using ammonites. Other fossil groups are reviewed briefly, however, with request to their biochronologic resolution and correlation potential. Many papers have been published on Upper Jurassic ammonites and their chronostratigraphic resolution (see detailed discussion below). For a broad overview, the reader is referred to the papers of Cariou *et al.* (1997), Geyssant (1997) and Hantzpergue *et al.* (1997) for western Europe and the Mediterranean. Other important, partly regional compilations and revisions have been published by Sapunov (1979), Donovan *et al.* (1981), Krymholts *et al.* (1988), Malinowska *et al.* (1988), Enay *et al.* (1994) and Schlegelmilch (1994).

Boundaries of the Upper Jurassic Series

Lower boundary (Middle–Upper Jurassic Series boundary)

The lower boundary of the Oxfordian Stage is rather well-defined by ammonite zones and subzones and only requires more precise definition with respect to the lowermost faunal horizon, which then would characterise the beginning of the lowermost subzone (and zone) of the stage. Furthermore, it appears that the lower boundary is approximately (on a subzonal level) the same in Boreal and Mediterranean areas. Once the type faunal horizon has been chosen, then the problem of the type locality for the boundary will also have been solved. At present, this boundary lies in France between the uppermost horizon of the *Quenstedtoceras lamberti* Zone of the Upper Callovian Substage (the *Cardioceras paucicostatum* horizon) and the lowermost horizon of the *Q. mariae* Zone; this was first named in France after *Peltoceratoides elisabethae* (Fortwengler & Marchand 1994a), but afterwards was changed to *Hecticoceras* (*Brightia*) *thouxense* (Fortwengler & Marchand 1994b, c), a species described only recently (Fortwengler *et al.* 1997). In Dorset, however, *Cardioceras* cf. *woodhamense* and *C. woodhamense* are found in the lowermost levels of the *Q. mariae* Zone (Callomon & Cope 1996), whereas in north-west France, *C. woodhamense* has been collected only in the third horizon of the *Q. mariae* Zone (Vidier *et al.* 1993). In south-east France, this horizon is only recognised tentatively. These different faunal horizons all lie

Submediterranean Province			
Stages	Substages Germany	Substages France	Basal zones of substages
Tithonian	Upper	Upper	Abnormis
	Middle	Lower	Semiforme
	Lower		Hybonotum
Kimmeridgian	Upper	Upper	Beckeri
	Middle		Acanthicum
	Lower	Lower	Platynota
Oxfordian	Upper	Upper	Bimammatum
	Middle		Bifurcatus
		Middle	Transversarium
	Lower	Lower	Mariae

Subboreal Province		
Basal zones of substages	Substages	Stages
Scythicus	Middle	Tithonian (Volgian)
Klimovi	Lower	
Autissiodorensis	Upper	Kimmeridgian
Mutabilis	Middle	
Baylei	Lower	
Glosense	Upper	Oxfordian
Plicatilis	Middle	
Mariae	Lower	

Fig. 1. Subdivision of the Upper Jurassic Series of Europe into stages, substages and zones. Substage usage varies in the literature, dependent on author; those indicated are only examples.

in the *Cardioceras scarburgense* Subzone, the lower subzone of the *Q. mariae* Zone, so that the age difference of these horizons (if any) should not be too large. A vote by the Callovian/Oxfordian Boundary Working Group in 1995 resulted in a preference for a type locality in south-east France, with the consequence that the Oxfordian would begin with the *H.(B.) thuouxense* horizon (see above), but a final decision was not taken (Meléndez 1995; Meléndez *et al.* 1998).

Upper boundary (Jurassic–Cretaceous System boundary)

In accordance with the decision of the ISJS (see above), there are two alternative stages for the uppermost part of the Jurassic System: Tithonian and Volgian. As they differ in duration, the boundary may be drawn at two different levels, i.e. there are two variants of the Jurassic–Cretaceous boundary. Accordingly, the members of the former Jurassic–Cretaceous Boundary Working Group agreed to work provisionally with two boundaries (Remane 1986; Remane *et al.* 1986; Zeiss 1986).

1. In Mediterranean and Submediterranean Europe, the boundary is placed between the top of the Tithonian Stage (top of *Durangites vulgaris* Zone and/or of Calpionellid Zone A) and the base of the Berriasian Stage (base of *Berriasella jacobi* Zone *s.l.* (= *Berriasella jacobi* and *Pseudosubplanites grandis* Subzones or *Pseudosubplanites euxinus* Zone) and/or base of Calpionellid Zone B).

2. In Subboreal and Boreal Europe, the boundary lies between the Upper Volgian (top of *Craspedites nodiger* or *Chetaites chetae* Zone) and the Ryazanian or 'Boreal Berriasian' (base of *Chetaites sibericus, Rjasanites rjasanensis* or *Runctonia runctoni* Zone) (Rawson *et al.* 1978; Kejsi *et al.* 1988; Sey & Kalacheva 1993a).

In the first case, the type locality should be best selected in south-eastern France, where the Ardescian Substage (Upper Tithonian) and the Berriasian Stage were originally described. Subsequent studies have revealed that the sequences are not complete at the base, however, so that it has been suggested that the best sections illustrating the Jurassic–Cretaceous boundary beds and their fauna are situated in southern Spain (Enay & Geyssant 1975; Tavera 1985; Tavera *et al.* 1994; Enay *et al.* 1998a, b).

In the second case, the boundary should correspond to the base of the *Berriasella boissieri* Zone in the Mediterranean area. Thus, the Upper Volgian Substage corresponds to the Lower Berriasian (Zeiss 1974, 1979, 1983, 1986; Rawson *et al.* 1978; Hoedemaker 1990; Sey & Kalacheva 1993a; W.A. Wimbledon in: Callomon & Cope 1996), and is not equivalent to the Upper Tithonian as Mesezhnikov (1988) and other authors have assumed.

In a recent review of the Berriasian Stage, Hoedemaker (1994) stated that the Jurassic–Cretaceous boundary is typically placed at one of two different levels, either at the base or at the top of the *Jacobi* Chronozone: "Investigators of Jurassic stratigraphy prefer the lower of these two boundaries, investigators of the Cretaceous stratigraphy the upper" (Hoedemaker 1994, p. 12).

At the same time, there has also been an attempt to trace the Jurassic–Cretaceous boundary based on geomagnetic anomalies from the Tethys to southern England (Ogg *et al.* 1994). In the Tethyan–Atlantic faunal realm, the top of magnetic polarity reversal M19r approximately coincides with the Tithonian–Berriasian boundary in the Mediterranean area. This reversal is difficult to place precisely in England, but it seems to be situated in the lowermost Purbeck beds. If so, it would demonstrate once again that the 'Upper Volgian' (Casey 1973) or 'Upper Portlandian' of England (Wimbledon 1980), i.e. the zonal sequence *Subcraspedites primitivus – Subcraspedites lamplughi*, overlaps with the Lower Berriasian.

Wimbledon (1980) also included the 'Upper Volgian' zones of Casey (1973) in the 'Portlandian' of Britain, thus extending the stage upwards by three further zones (termed here 'Upper Portlandian'). In a recent compilation chart, W.A. Wimbledon (in: Callomon & Cope 1996) correlated these 'Upper Portlandian' zones and the Upper Volgian zones of the Russian platform with parts of the Lower Berriasian.

In Poland, the Jurassic–Cretaceous boundary has been traced by joint studies of ostracodes and ammonites (Marek *et al.* 1989) whereby the Upper Tithonian and the lower part of the Lower Berriasian could be recognised as well as the Upper Berriasian (= 'Ryazanian'). In a recent paper (Marek & Shulgina 1996), the ammonites of the Berriasian (Ryazanian) were considered to belong to the interval upper *occitanica* – lower *boissieri* Zones.

In a recent development, the Interdepartmental Stratigraphic Committee of Russia (ISC) approved the following resolutions of its commissions on the Jurassic and Cretaceous Systems (Rostovtsev & Prozorovskiy 1997, p. 48).

"1. To draw the Jurassic–Cretaceous boundary in the Boreal Realm between the middle and upper substages of the Volgian, and not ...... as ...... earlier adopted in Russia (1978). This boundary mainly corresponds to the Tithonian/Berriasian boundary in Tethyan realm (Colloque Lyon–Neuchâtel, 1975). Correspondingly, the Lower Volgian in the whole correlated with the Lower and Middle Tithonian; the Middle Volgian, with the Upper Tithonian; the Upper Volgian, with two lower zones of the Berriasian (Jacobi/Grandis and Occitanica).

2. To transfer the Volgian Stage in its former range to the category of regional stratigraphic units (regional stage). To distinguish as chronostratigraphic units in the boundary part of the Jurassic and Cretaceous scale of Russia only Tithonian and Berriasian."

These resolutions, which were precipitated by the work of Sey & Kalacheva (1993a), confirmed the earlier opinions of many authors concerning Upper Jurassic/Lower Cretaceous correlations.

It is clear that general consensus has not yet been reached; it is assumed, however, that the present Tithonian–Berriasian boundary is not suitable for global correlation. It may be preferable, therefore, to return to an old proposal: to define the Jurassic–Cretaceous boundary at the base of the *B. boissieri* Zone, where many guide fossils of different groups are available for correlation. Recent studies in the Caucasus area by Remane (1997) are supportive of this proposal.

Upper Jurassic stages – subdivision and correlation

Oxfordian (Figs 2, 3)

The Colloquium at Luxembourg in 1962 (Maubeuge 1964, p. 85) came to the resolution "...... that it seemed necessary to return to the original sense of this stage

			Submediterranean								Subboreal		Boreal			
			France, Spain		Switzerland		S. Germany				England		Greenland, Scotland, Svalbard			
154.1 (± 3.2)	Oxfordian	Upper	Planula (Grandiplex)	Galar (Gigantoplex, Grandiplex)		Galar	Galar					?	?		(? Bayi)	↓ (Sub-)Boreal Ox./Ki. boundary
										Bauhini	Baylei	Baylei	Ravni	Bauhini		
				Praecursor	Planula	Planula	Planula	Praecursor								
				Tonnerense				Planula	Ringsteadia							
								Proteron								
												Densicostata				
			Bimammatum	Hauffianum	Bimammatum		Bimammatum	Bauhini								
								Hauffian.								
											Pseudocordata	Evoluta		Rosen-krantzi		
				Bimammatum				Bimam-matum								
				Berrense				Berrense				Pseudocordata				
				Semimammatum				Hypsel.		Ovale		Pseudoyo				
		Middle	Bifurcatus	Grossouvrei	Bifurcatus	Grossouvrei	Bifurcatus					Caledonica		Regulare		
											Cautisnigrae	Variocostatum				
				Stenocycloides		Stenocycloides							Serratum		Serratum	
												Cautisnigrae			Koldewayense	
			Transversarium	Rotoides		Schilli	Transversarium	Schilli		Alternans			Glosense (Alternoides)		Glosense	
				Schilli												
											Pumilus	Nunning-tonense				
															Ilovaiskyi	
				Luciaeformis (Wartae)	Transversarium	Parandieri		Transver-sarium								
												Parandieri				
				Parandieri									Tenuiserratum		Blakei	
			Plicatilis	Antecedens		Antecedens	Plicatil.	Antecedens			Plicatilis	Antecedens			Tenuiserratum	
				Vertebrale		Densiplicatum		Vertebrale				Vertebrale	Densiplicatum		Maltonense	
															Vertebrale	
		Lower	Cordatum	Cordatum	Cordatum	Cordatum	Cordatum	Cordatum			Cordatum	Cordatum	Cordatum		Cordatum	
				Costicardia		Costicardia		Costicardia				Costicardia			Costicardia	
				Bukowskii		Bukowskii		Bukowskii				Bukowskii			Bukowskii	
			Mariae	Praecordatum	Mariae	Praecordatum	Mariae	Praecordatum			Mariae	Praecordatum	Mariae		Praecordatum	
159.4 (± 3.6)				Scarburgense		Scarburgense		Scarburgense				Scarburgense			Scarburgense	

Fig. 2. A tentative correlation chart for the Oxfordian Stage in Europe (**thick** lines indicate periods during which correlation is difficult). Modified after Zeiss (1984), Mesezhnikov (1988), Cariou *et al.* (1991b), Wright (1996a, b), Matyja & Wierzbowski (1997, 1998), Schweigert & Callomon (1997) and Gygi (2000a, b).

[the Oxfordian] as defined by A. d'Orbigny and given precision by W.J. Arkell (1956)". The 'base' was indicated to be the 'Zone of *Quenstedtoceras mariae*' and the 'top' the 'Zone of *Ringsteadia pseudocordata* (= Zone of *Idoceras planula*), (= Zone of *Epipeltoceras bimammatum*)'. It was recommended that other stage and substage names then still in use, e.g. the Argovian (Marcou 1848), Rauracien (Greppin 1867), Sequanian (Marcou 1848) and the Lusitanien (Choffat 1885; Haug 1910) should be abandoned. These stages had been interpreted in different ways so that continued usage would have created only more confusion. Subsequent studies (e.g. Enay 1980a; Gygi & Persoz 1986; Enay *et al.* 1988) demonstrated the validity of this resolution.

Lower boundary

See discussion above.

Substages

Although the Oxfordian has been subdivided into three substages, Lower, Middle and Upper Oxfordian, full agreement has not been reached on the zonal content of these substages and the position of their boundaries (Callomon 1988, 1990, fig. 10; Meléndez & Fontana 1993, fig. 5; Wright 1996a). The subdivision is thus essentially informal but the substages are capitalised in

<table>
<tr><th colspan="2">Submediterranean Standard
(Cariou <i>et al.</i> 1991b)</th><th colspan="2">Spain – North Africa
(Sequeiros 1974; Cariou <i>et al.</i> 1991b)</th><th colspan="3">Poland
(Tarkowski 1990; Matyja & Glowniak 1994)</th><th>Bulgaria
(Sapunov 1976)</th></tr>
<tr><td rowspan="4">Trans-versarium</td><td>Rotoides</td><td rowspan="4">Riazi</td><td rowspan="5"></td><td rowspan="6">Trans-versarium</td><td rowspan="4" colspan="2">Wartae</td><td rowspan="4">Riazi</td></tr>
<tr><td>Schilli</td></tr>
<tr><td>Luciaeformis</td></tr>
<tr><td>Parandieri</td></tr>
<tr><td rowspan="4">Plicatilis</td><td rowspan="2">Antecedens</td><td>Antecedens</td><td rowspan="2" colspan="2">Antecedens</td><td rowspan="2">Antecedens</td></tr>
<tr><td rowspan="5">Paturattensis</td><td rowspan="3">Magnouatius</td></tr>
<tr><td rowspan="2">Vertebrale
(Tenuicostatum)</td><td rowspan="2">Plicatilis</td><td colspan="2">Promiscuus</td><td rowspan="2">Episcopalis</td></tr>
<tr><td rowspan="2">Patu-rattensis</td><td>Helenae</td></tr>
<tr><td rowspan="5">Cordatum</td><td rowspan="2">Cordatum</td><td rowspan="2">Paturattensis</td><td rowspan="3">Paturattensis</td><td></td><td rowspan="5">Renggeri</td></tr>
<tr><td rowspan="2" colspan="2">Oculatum</td></tr>
<tr><td rowspan="2">Costicardia</td><td rowspan="3">Claro-montanus</td><td rowspan="2">Mazuricus</td></tr>
<tr><td rowspan="4">Minax</td><td rowspan="2" colspan="2">Baccatum</td></tr>
<tr><td>Bukowskii</td><td>Claro-montanus</td></tr>
<tr><td rowspan="2">Mariae</td><td>Praecordatum</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2" colspan="2">Spixi</td><td rowspan="2">Athletoides</td></tr>
<tr><td>Scarburgense</td></tr>
</table>

Fig. 3. A tentative correlation chart for some alternative subdivisions of parts of the Oxfordian Stage in Mediterranean and Submediterranean Europe.

this paper, following common usage. An example of the ongoing debate is the inclusion of the *D. bifurcatus* Zone in the Middle or Upper Oxfordian; this zone was introduced by Enay (1966) as the upper subzone of the *G. transversarium* Zone but was later considered as the lowermost zone of the Upper Oxfordian (Cariou *et al.* 1971). Preference is given here to a subdivision in which the *D. bifurcatus* Zone is included in the Middle Oxfordian (Fig. 1) as has also been proposed by Meléndez (1989), Cariou & Meléndez (1990), Cariou *et al.* (1991a) and Gygi (2000a) although not followed by Cariou *et al.* (1991b, 1997).

While the lower and middle substages have the same lower boundaries in Submediterranean and Subboreal Europe, the position of the lower boundary of the upper substage differs. In Boreal Europe, it has been drawn at three different levels (Wright 1996a, fig. 6). The solution to draw it at the base of the *A. glosense* Zone is well-known (Sykes & Callomon 1979; Wright 1980); it would correspond to the base of the *P. luciaeformis* Subzone in the *G. transversarium* Zone, i.e. the boundary would be drawn around one and a half zones deeper than in the Submediterranean subdivision. It seems preferable to draw the boundary at the lower boundary of the *A. rosenkrantzi* Zone, corresponding approximately to the lower boundary of the Upper Oxfordian both in Submediterranean Europe (base of *E. bimammatum* Zone) and in Subboreal Europe (base of *R. pseudocordata* Zone), although the latter lies somewhat deeper (Matyja & Wierzbowski 1997, fig. 4).

Additional literature references pertinent to the subdivision of the Oxfordian Stage are Enay (1963, 1966), Zeiss (1966), Sequeiros (1974), Sapunov (1976), Gygi (1977, 1986, 1990a, 2000a, b, c), Wierzbowski (1978), Enay & Meléndez (1984), A. Zeiss (in: Enay & Meléndez 1984), Cariou & Meléndez (1990), Malinowska (1991), Meléndez & Fontana (1993), Schweigert (1995a, b), Fözy & Meléndez (1996), Matyja & Wierzbowski (1997, 1998), Groiss *et al.* (2000) and Schweigert & Callomon (1997) for the Submediterranean and Mediterranean provinces, and Sykes & Callomon (1979), Wright (1980, 1996a, b) and Mesezhnikov (1988) for the Subboreal and Boreal provinces. Mönning & Bertling (1995), Mönning (1998) and Gramann *et al.* (1997) have presented interesting and useful reviews of the ammonite succession in northern Germany.

Zones

The zonal and subzonal subdivision of the Lower Oxfordian Substage was established by Arkell (1941) using *Quenstedtoceras mariae* and *Cardioceras cordatum* as index species; it can be used over large areas of northern and central Europe (Fig. 1) and is also applicable in the Dauphinois basin of south-east France as recently demonstrated by Fortwengler & Marchand (1994a; Fortwengler *et al.* 1995).

In southern Europe, a variety of subdivisions exist; at least three distinct subdivisions testify to the difficulties in erecting a generally accepted zonal scheme if cardioceratids are missing. In such cases, peltoceratids (*Peltomorphites*, *Peltoceratoides* and *Parawedekindia*), oppeliids (*Taramelliceras, Popanites* and *Creniceras)* and perisphinctids (*Otosphinctes, Perisphinctes, Prososphinctes* and *Properisphinctes*) are important guide fossils (see Fig. 3), e.g. *Taramelliceras minax, T. spixi, T. baccatum, T. oculatum, Popanites paturattensis* in Poland (Tarkowski 1990)*, Peltomorphites athletoides* and *Creniceras renggeri* in Bulgaria (Sapunov 1976), and *Prososphinctes mazuricus* and *P. claromontanus* in Spain (Aurell *et al.* 1990).

From the base of the Middle Oxfordian, perisphinctids and peltoceratids become the dominant ammonite groups with respect to index fossils at the substage level in the Submediterranean and Subboreal provinces. The first aulacostephanids (*Decipia*) also appear at this level. The *Perisphinctes plicatilis, Gregoryceras transversarium* and *Dichotomoceras bifurcatum* Zones make up the Middle Oxfordian Substage in the Submediterranean area, the *Perisphinctes plicatilis, P. pumilum* and *P. cautisnigrae* Zones are representative of the Subboreal province. Boreal indexes are *Cardioceras tenuicostatum* and *C. tenuiserratum, Amoeboceras glosense* and *A. serratum.* The correlation between Subboreal perisphinctid and amoeboceratid zones was well demonstrated by Wright (1996b).

There is a difference in the usage of the *P. plicatilis* and *G. transversarium* Zones in Submediterranean Europe. Although Gygi & Marchand (1982) replaced the basal *C. vertebrale* Subzone with the *C. densiplicatum* Zone and included the *P. antecedens* Subzone in the *G. transversarium* Zone, subsequent authors have not followed the arguments of these authors and have continued to use the *P. plicatilis* Zone in the sense of Cariou *et al.* (1991a, b), i.e. with *C. vertebrale* and *P. antecedens* Subzones (e.g. Meléndez & Fontana 1993, fig. 4; Cariou *et al.* 1997). Cariou *et al.* (1991a) defined the *G. transversarium* Zone to contain the *P. parandieri, P. luciaeformis, L. schilli* and *P. rotoides* Subzones. In a more recent publication, Gygi (1995) included in the lower part of the *G. transversarium* Zone not only the *P. antecedens* Subzone but also the *C. densiplicatum* Subzone i.e. the whole *P. plicatilis* Zone (following the original usage of Oppel & Waagen 1866; R.A. Gygi, personal communication 1997). In further contributions to the Upper Jurassic of Switzerland (Gygi 2000b, c), the *G. transversarium* Zone is subdivided into the *C. densiplicatum, P. antecedens*, and *P. luciaeformis* Subzones; the overlying *D. bifurcatus* Zone contains in its lower part the *L. schilli* Subzone, which is considered in Spain and France to represent the upper part of the *G. transversarium* Zone (see above). The main reason for these differences is the occurrence of *L. schilli* in Switzerland above the vertical range of *G. transversarium.*

The Upper Oxfordian Substage in Submediterranean Europe comprises the *Epipeltoceras bimammatum, Idoceras planula* and *Sutneria galar* Zones. Considering the new correlations of Wright (1996a), Matyja & Wierzbowski (1997) and Cariou *et al.* (1997), *Ringsteadia pseudocordata* would be the corresponding index fossil for the Subboreal province, whereas *Amoeboceras rosenkrantzi* would be the index fossil for Boreal Europe.

The *Amoeboceras serratum* Zone of Malinowska (1991) contains *Epipeltoceras* (*uhligi* group) and *Ringsteadia salfeldi* thus indicating, at least partly, equivalence with the lower *E. bimammatum* Zone (*E. hypselum* Subzone); this demonstrates that the *A. serratum* Zone of this author is younger in age than the *A. serratum* Zone of Sykes & Callomon (1979). The *A. regulare* Subzone of Malinowska (1991) seems to represent the upper *E. bimammatum* and perhaps the lowermost *I. planula* Zones, while the *A. lineatum* Subzone apparently corresponds to the rest of the *I. planula* Zone and the *S. galar* Zone.

The most difficult problems associated with these Upper Oxfordian zones concern their correlation in the Subboreal and Submediterranean schemes; this aspect is discussed in detail below. Some minor problems may be caused by the different hierarchical status of zones and subzones in the Subboreal and Boreal provinces. For example, Atrops *et al.* (1993b) recognised the *A. regulare, A. rosenkrantzi* and *A. bauhini* Zones, whereas Malinowska (1991) subdivided the *R. pseudocordata* Zone into the *A. regulare* and *A. lineatum* Subzones or, in Boreal Europe, into the *A. regulare* and *A. rosenkrantzi* Subzones. However, comparing the correlation chart of Malinowska (1991, table 3) with that of Matyja & Wierzbowski (1997, fig. 3), it becomes evident that the *P. pseudocordata* Zone of Malinowska corresponds only to the upper part of the *A. regulare*, the *A. rosenkrantzi* and the *P. baylei* Zones.

Another example is the variable status of *A. bauhini* as an index species. There is the *A. bauhini* horizon in the upper *E. bimammatum* zone equivalent to the *P. densicostata* horizon (Schweigert & Callomon 1997), the *A. bauhini* Subzone of the *A. rosenkrantzi* Zone (Sykes & Callomon 1979; Cariou *et al.* 1997), equivalent to the *P. baylei* Zone of Birkelund & Callomon (1985), and the *A. bauhini* Zone. Although initially equivalent to the *P. densicostata* horizon (Wierzbowski & Smelror 1993), the *A. bauhini* Zone was expanded by Matyja & Wierzbowski (1997, 1998) to correlate with the uppermost *P. pseudocordata* Zone and nearly the whole *P. baylei* Zone on the one hand and with the whole *I. planula* Zone and uppermost *E. bimammatum* Zone on the other; a little more restricted was the *A. bauhini* Zone of Schweigert & Callomon (1997), who excluded the *S. galar* Subzone of the *I. planula* Zone (see below).

Correlation

There have been many proposals and attempts to correlate the zonal subdivisions of the Oxfordian of Mediterranean, Submediterranean, Subboreal and Boreal areas of Europe; the most important ones have been already discussed in the text above (see Figs 2, 3). Further informative compilations have been presented by Enay & Meléndez (1984), Mesezhnikov (1988), Cariou *et al.* (1991a, b; 1997), Malinowska (1991), Aleynikov & Meledina (1993), Meléndez & Fontana (1993), Schweigert (1995b), Wright (1996a, b) and Matyja & Wierzbowski (1997). In short, correlation within the Lower Oxfordian is possible over wide regions of Boreal, Subboreal and Submediterranean Europe, but becomes difficult on approaching the Mediterranean area.

At the base of the Middle Oxfordian, ammonites of the *Perisphinctes plicatilis* Zone provide the last possibility for long-distance correlation. Higher up in the Middle Oxfordian, zonal correlations become more and more difficult, best illustrated by the charts of J.H. Callomon (in: Wright 1980), Enay & Meléndez (1984) and Cariou *et al.* (1991b; see also Fig. 2). The divergent views are also well-documented by the tables of Malinowska (1991), Wright (1996a), Cariou *et al.* (1997) and Matyja & Wierzbowski (1997).

The problems of Upper Oxfordian correlation, concentrated mainly on the correspondence of the *E. bimammatum, I. planula* and *S. galar* Zones to the *R. pseudocordata, P. baylei, A. regulare, A. rosenkrantzi* and *A. bauhini* Zones, are under discussion (Wierzbowski 1991; Atrops *et al.* 1993b; Atrops & Meléndez 1994b; Schweigert 1995a, b; Cariou *et al.* 1997; Matyja & Wierzbowski 1997; Schweigert & Callomon 1997). This aspect is especially relevant to the Oxfordian–Kimmeridgian boundary problem and is therefore discussed in more detail below.

Chronometric data

The duration of the Oxfordian Stage is estimated at 5.3 Ma (Gradstein *et al.* 1995; Ogg 1995; Ogg & Gutowski 1996); for precise data, see Figure 2.

Kimmeridgian (Fig. 4)

Following the Luxembourg recommendations of 1962 and 1967 (Maubeuge 1964, 1970), two possibilities existed with respect to usage of the Kimmeridgian Stage, namely either a long version ('*sensu anglico*') or a short version ('*sensu gallico*'), both with differing zonal content and boundaries (see below). Use of two different versions of the Kimmeridgian evoked much confusion in following years and led to endless discussion. Therefore a vote of the International Subcommission on Jurassic Stratigraphy (ISJS) on this question was arranged in 1990, simultaneously with the vote on the Tithonian Stage (see below); the members of the ISJS voted for a 'short' version of the Kimmeridgian Stage (i.e. '*sensu gallico*'). This meant that in future the upper boundary of the Kimmeridgian Stage should be coincident with the lower boundary of the Tithonian Stage and its Boreal equivalent, the Volgian (Zeiss 1991a). The lower boundary of the stage, however, remained ambiguous (see below).

Because of the still unresolved problems at the Oxfordian–Kimmeridgian boundary, the lower boundary of the Kimmeridgian Stage is drawn in this paper at the base of the *Sutneria platynota* Zone, following the above-mentioned adoption of a short Kimmeridgian Stage (i.e. '*sensu gallico*' or according to the 'continental' concept; Enay 1980b). The Working Group of the Oxfordian–Kimmeridgian Boundary is mandated to finally define the boundary at a level which allows far-reaching correlations and corresponds to the resolutions of the International Commission on Stratigraphy (ICS); see also the discussions by Wierzbowski (1999, 2001).

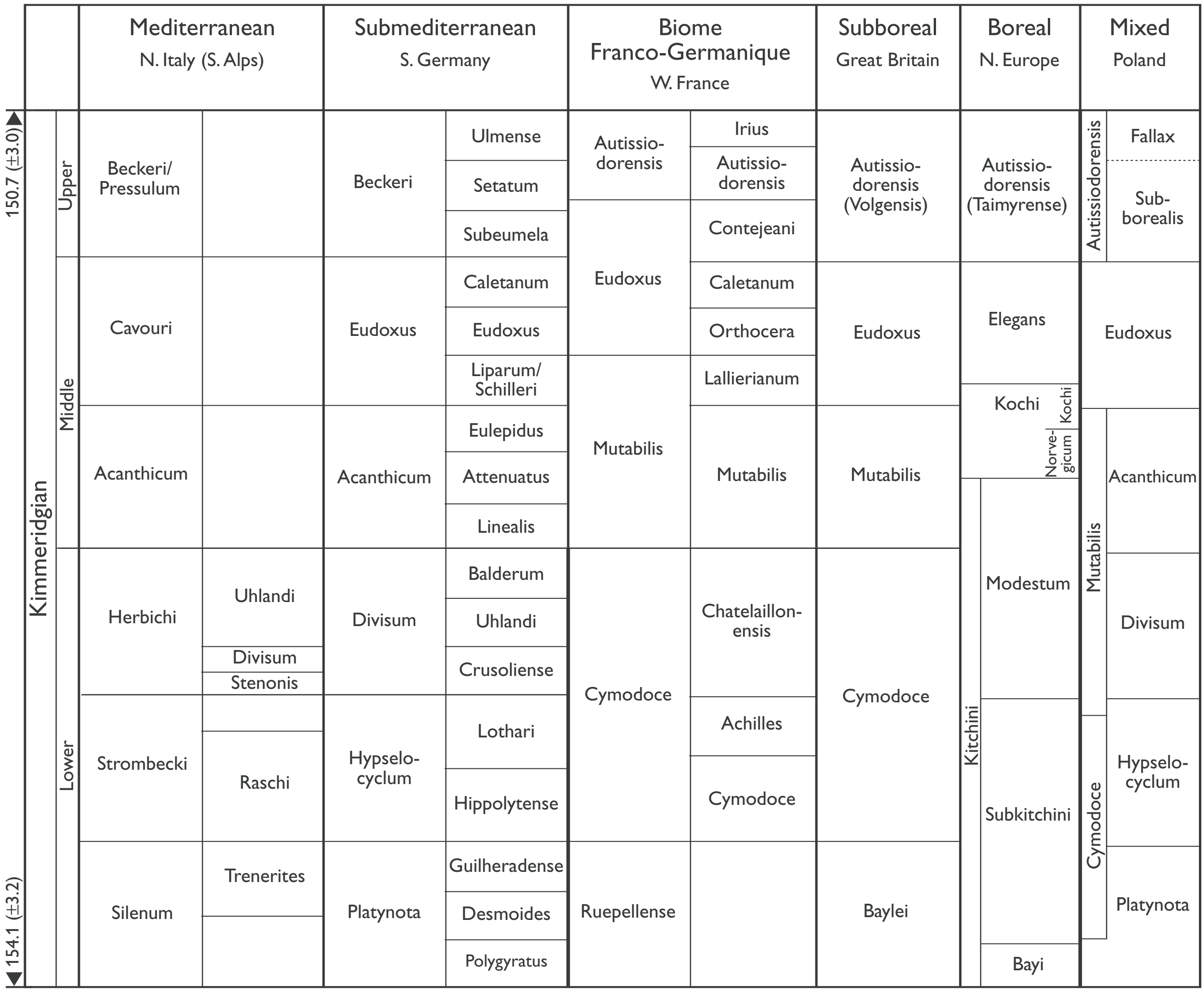

Fig. 4. A tentative correlation chart for the Kimmeridgian Stage in Europe (**thick** lines as in Fig. 2). Modified after Zeiss (1965), Atrops (1982), Sarti (1988), Hantzpergue *et al.* (1991), Wierzbowski & Smelror (1993), Kutek & Zeiss (1994), Schweigert & Zeiss (1994) and Matyja & Wierzbowski (1997, 1998).

Until such a definition has been taken by the Oxfordian–Kimmeridgian Boundary Working Group, voted on by the ISJS and approved by ISC, it seems useful to maintain the traditional boundaries in both biogeographic provinces, and it is premature to draw the Oxfordian–Kimmeridgian boundary in the Submediterranean area in the upper part of the *E. bimammatum* Zone (cf. Gygi 2000a, b).

Lower boundary

As the Luxembourg recommendations made it possible to select between two distinct versions of the Kimmeridgian Stage, the lower boundary was also defined twofold. In Subboreal regions of Europe, the boundary was drawn at the lower boundary of the *Pictonia baylei* Zone, whereas in Submediterranean regions it was placed at the base of the *Sutneria platynota* Zone (Maubeuge 1964, p. 85–86). At that time, it was supposed that both boundaries were more or less isochronous (Ziegler 1964), although doubts remained (e.g. Zeiss 1965; Cariou *et al.* 1971).

With the publication of Sykes & Callomon (1979), new impetus was given to further studies, which have suggested that the assumed time equivalence is erroneous or, at best, only partially true (Matyja & Wierzbowski 1988; Wierzbowski 1991; Atrops *et al.* 1993b; Schweigert 1995a, b). The main reasons for this view were the discovery of new *Amoeboceras* faunas by these authors and a re-evaluation of Salfelds (1915) *Cardioceras* paper as well as that of Koerner (1963), particularly with respect to their remarks concerning the type locality and possible type horizon of *Cardioceras* (= *Amoeboceras*) *bauhini*. The discussion of Wierzbowski (1991) concerning the range of the genus *Ringsteadia* in Poland is also important in this context. It soon became evident that *Amoeboceras bauhini* has its type horizon just below the upper boundary of the *E. bimammatum* Zone, (see A. Zeiss in: Enay & Meléndez 1984). The studies of Schweigert (1995a, b; Schweigert & Callomon 1997) resulted in similar conclusions, but led to a more precise faunal horizon subdivision of the Upper Oxfordian in Württemberg, SW Germany and to better correlation possibilities with England, with respect to the *A. bauhini* and the *A. bayi* (?= *A. subtilicaelatum*) horizon.

Some problems remained unsolved, however:

1. Does the *A. bauhini* horizon of southern Germany represent the same time interval as the beds bearing *A. bauhini* in England, Scotland and the Barents Sea? Or is there a difference, and the vertical range of this species is different in these two areas? What is the situation in Poland, representing an intermediate region?

2. Does the *A. subtilicaelatum* horizon of southern Germany represent the same time interval as the *A. bayi* horizon in England? Or is there also a difference in the vertical range of these species in different parts of Europe?

3. Which units in the Subboreal realm correspond to the succession from the base of the *I. planula* Zone (with three or four faunal horizons) and the top of the lower *S. galar* Zone, which in Submediterranean Europe occurs between the *A. bauhini* and the *A. subtilicaelatum* (?= *A. bayi*) horizon?

It is not easy to answer these questions given the present state of knowledge; the following points are pertinent prior to discussion of these problem areas. The usage of *A. bauhini* as an index ammonite began with its introduction by Sykes & Callomon (1979) as a subzone of the *A. rosenkrantzi* Zone (uppermost Oxfordian); its stratigraphic position was subsequently revised by Birkelund & Callomon (1985), who regarded the *A. bauhini* Subzone and the *P. baylei* Zone (Lower Kimmeridgian) as approximate equivalents. One year prior to this latter publication, A. Zeiss (in: Enay & Meléndez 1984, fig. 6) had used *A. bauhini* informally as a zonal index in a correlation chart to show its approximate correspondence with the *I. planula* Zone *sensu lato*; this view was also held by Atrops *et al.* (1993b) and Matyja & Wierzbowski (1997, 1998). Wierzbowski & Smelror (1993) established the *A. bauhini* Zone formally and suggested that it was equivalent to only the lower part of the *P. baylei* Zone (the *P. densicostata* horizon); in more recent papers, Matyja & Wierzbowski (1994, 1995, 1997, 1998) provided charts showing the correlation between the *A. bauhini* Zone and the *I. planula* Zone *sensu lato* as well as with the *P. baylei* Zone (with the exception of the uppermost part). Finally, in southern Germany, an *A. bauhini* horizon was described by Schweigert (1995b; Schweigert & Callomon 1997) in the upper part of the *T. hauffianum* Subzone (uppermost *E. bimammatum* Zone); the latter authors correlated the Boreal *A. bauhini* Zone with the *I. planula* Zone *sensu stricto*, whereas the *S. galar* Zone was correlated with the *Amoeboceras kitchini* Zone.

The *Amoeboceras bayi* horizon was introduced by Birkelund & Callomon (1985) in the upper part of the *P. baylei* Zone, whereas Wierzbowski & Smelror (1993) reported the species at the base of their *A. subkitchini* Subzone. Atrops *et al.* (1993b) found the species, or closely related forms, in the *Sutneria platynota* Zone of the Submediterranean area. Schweigert (1995b) established an *A. subtilicaelatum* horizon in the uppermost part of the *Sutneria galar* Zone, assuming that *A. bayi* is only a variant of *A. subtilicaelatum*, which would then have priority. This conflicts with the opinion of Salfeld (1915), that *A. lineatum* and *A. subtilicaelatum* are very close and perhaps synonymous. Schweigert (1995b) also assumed that many specimens determined earlier as '*A. bauhini*' belong in reality to *A. bayi*. To verify these assumptions, a comprehensive re-evaluation of the Upper Oxfordian – Lower Kimmeridgian *Amoeboceras* species complex (*A. bauhini* – *A. bayi* – *A. subtilicaelatum* – *A. lineatum*) would be necessary. Such a study should also illustrate the variation within each species in time and space (see, for example, Klieber 1981; Birkelund & Callomon 1985; Matyja & Wierzbowski 1988, 1994; Schweigert & Callomon 1997).

For the time interval of the *I. planula* Zone, Malinowska (1991) established the *A. lineatum* Subzone in Poland. It was introduced as the upper subzone of the *R. pseudocordata* Zone, but the precise correlation with other areas is not clear; from the list of fossils one would conclude that the *S. galar* Zone is not present. However, as a *Sutneria* sp. (of the *galar/praecursor* group?) is mentioned in the text but not figured, a decision is difficult; its low stratigraphic level in the Goldap section would favour the *S. praecursor* Zone. In addition, Wierzbowski (1978) has described *A. lineatum* and *A. bauhini* together from the lower part of the *I. planula* Zone; thus, the *A. lineatum* Subzone seems to correspond to the lower part of the *P. baylei* Zone rather than to the upper part of the *R. pseudocordata* Zone. Malinowska (1988) reported specimens of *A. bauhini* only from the Lower Kimmeridgian, but these forms belong to other species such as *A. bayi* or *A.* cf. *cricki*.

In the Subboreal province, the *Pictonia baylei* Zone consists of two or three horizons. The lowermost horizon in Great Britain and the Boulonnais area is the *Pictonia densicostata* horizon; as mentioned above, this probably corresponds to the *A. bauhini* horizon. In the Boulonnais and Normandy areas, this is followed by the *Pictonia baylei* horizon *sensu stricto*, and, more widespread in France, the *P. baylei* and *P. thurmanni* horizon. In Dorset, the second horizon is apparently missing (Hantzpergue 1989), while the third one is represented by the *P. baylei* and *P. normandiana* horizon, which can also be observed in East Greenland (*P.* aff. *normandiana* horizon, Birkelund & Callomon 1985). *P. normandiana* is regarded as a synonym of *P. thurmanni* by Hantzpergue (1989). This third horizon also contains *A. bayi*.

What conclusions can be made from all these observations?

1. It seems likely that *A. bauhini* has a longer range in south Germany, as suggested by the many records of this ammonite species from the *E. hypselum* Subzone of the *E. bimammatum* Zone to the *I. planula* and *S. galar* Zones and even from the *S. platynota* Zone; a number of these determinations, although probably not all, may however be erroneous (Schweigert 1995b). Data from Poland also demonstrate that the range of *A. bauhini* is not restricted to the upper *T. hauffianum* Zone (= *A. bauhini* horizon), but extends as in southern Germany from the upper *E. hypselum* Subzone of the *E. bimammatum* Zone to the top of the *I. planula* Zone *sensu lato* (Matyja & Wierzbowski 1997, 1998). It is likely, therefore, that the *A. bauhini* Zone is of longer duration in the Submediterranean area, because it comprises not only the *A. bauhini* horizon of the upper *T. hauffianum* Subzone, but also three or four horizons of the *I. planula* Zone *sensu stricto* and at least one horizon of the lower *S. galar* Zone. As mentioned above, Malinowska (1991, p.16–17) apparently introduced the term *A. lineatum* Subzone for such an extended *A. bauhini* Zone. Approximately the same time interval has been called the *A. bauhini* Subzone (of an unnamed zone) by Matyja & Wierzbowski (1994, 1995) and subsequently elevated to the *A. bauhini* Zone (Matyja & Wierzbowski 1997, 1998); this zone is now correlated with the upper *E. bimammatum* Zone and the *I. planula* Zone *sensu lato*. It should also be noted that there is some evidence, at least in Scotland, that above the *P. densicostatum* bed follows another, younger bed with *A. bauhini* and *Pictonia* sp. (Wright 1989). This could be a hint that there are some more beds with *A. bauhini*, but without *P. densicostata*, which could correspond to the higher horizons of the *P. baylei* Zone.

   In England, in contrast, Cox & Richardson (1982) observed *A. bauhini* in the uppermost part of the *A. rosenkrantzi* (= *R. pseudocordata*) Zone. If these determinations are correct, *A. bauhini* may occur a little earlier than the *P. densicostata* horizon. One can conclude from these observations that the range of *A. bauhini*, even in the Subboreal regions, is not restricted to the *P. densicostata* horizon or the '*A. bauhini* Zone' *sensu* Wierzbowski & Smelror (1993).

2. If it can be confirmed that *Amoeboceras bayi* and *Amoeboceras subtilicaelatum* are synonymous, as assumed by Schweigert (1995b), then the upper horizon of the *Sutneria galar* Zone (*A. subtilicaelatum* horizon) may correspond to the *Amoeboceras bayi* horizon of the lowermost Kimmeridgian *Amoeboceras kitchini* Zone. It should be noted, however, that *A. bayi* has also been reported from the lower ('*Orthosphinctes*') horizon of the *S. platynota* Zone (Atrops *et al.* 1993b).

3. (a) It can be concluded from the above that correlation of the *A. bauhini* and *P. densicostata* horizon with the *A. subtilicaelatum* and *A. bayi* horizon is possible, but the vertical ranges of the former species may be longer and the correlation may thus be only partial. Consequently, the position of the upper boundary of the *A. bauhini* Zone and the lower boundary of the *A. bayi* horizon require more precise definition.

   (b) In the sequence between the *A. bauhini* and the *A. subtilicaelatum* horizons, equivalent to the middle part of the *Pictonia baylei* Zone, the *P. baylei* horizon of Normandy and the upper *A. bauhini*-bearing beds in Scotland (e.g. bed 38 with *Pictonia* sp., Wright 1989) could be expected. They may have their equivalents anywhere in this succession, whereas other parts of the Submediterranean succession are not represented in the Subboreal sections or only by gaps.

(c) The inclusion of this part of the Submediterranean subdivision in an *A. lineatum* Subzone (Malinowska 1991) with its unprecise limits (in southern Germany, the species is known to occur in the Upper Oxfordian and Lower Kimmeridgian) will not help significantly; this subzone can be replaced by the *A. bauhini* Zone, as used by Matyja & Wierzbowski (1997, 1998).

(d) There are apparently different possibilities of correlation and further research is necessary to clarify the situation.

(e) The Subboreal Oxfordian–Kimmeridgian boundary (*R. pseudocordata/P. baylei* Zone) can, with a high degree of probability, be positioned within the Submediterranean and Mediterranean scheme in the uppermost part of the *E. bimammatum* Zone on the basis of the correlation of the *A. bauhini* horizon with the *P. densicostata* horizon. The Submediterranean Oxfordian–Kimmeridgian boundary remains at the base of the *S. platynota* Zone.

Additional remarks on Lower Kimmeridgian correlation

As mentioned above, the upper *S. galar* Zone (*A. subtilicaelatum* horizon) is probably an equivalent of the *Amoeboceras bayi* horizon (Schweigert 1995a), which extends into the lower part of the *S. platynota* Zone (*Amoeboceras* horizon with *A. bayi,* see Atrops *et al*. 1993b). This contrasts somewhat with the correlation of Birkelund *et al*. (1983, table 1), who considered the *Pictonia baylei* Zone and the *Paraspidoceras rupellense* Zone of Hantzpergue (1979) to be equivalent. Hantzpergue (1989), too, correlated the *P. baylei* Zone with the *P. rupellense* Zone (horizons R1 and R2); horizons P1–3 of the *I. planula* Zone *sensu lato* are considered to be equivalent to the *R. pseudocordata* Zone *sensu lato* (Hantzpergue 1989, tables E, F). In his sections, he found the Upper Oxfordian *Sutneria galar* in the *Lithacosphinctes gigantoplex* horizon (P3), immediately below his *P. rupellense* Zone (see Fig. 2).

The *P. rupellense* Zone itself is situated between the *gigantoplex* horizon (P3) of the uppermost *Idoceras planula* Zone *sensu lato* and the *Rasenia cymodoce* Zone (Fig. 4); it is therefore considered to be equivalent to the lowermost Submediterranean Kimmeridgian (*S. platynota* Zone; Schairer 1970; Atrops 1982; Olóriz & Rodríguez-Tovar 1996); its lower horizon (R1) seems to correspond to the upper part of the lower ('*Orthosphinctes*') subzone of the *S. platynota* Zone, whereas the lower part (*Amoeboceras* horizon) of this zone is not represented; its upper horizon (R2) contains the index '*Ardescia virgatoides*', which is similar to forms of the *Ardescia desmoides* horizon of the *Ardescia desmoides* Subzone of the middle *Sutneria platynota* Zone and is therefore very important for correlation to the Submediterranean region.

Above the *P. ruppelense* Zone, Hantzpergue (1989) subdivided the *Rasenia cymodoce* Zone into nine horizons (C1–9); the *R. cymodoce* horizon (C2) could be traced from western France to Normandy and the Subboreal regions. In northern Europe, the *R. cymodoce* horizon is rather widespread (Wierzbowski 1989) and in Spitsbergen it represents the only rasenoid horizon within the *Amoeboceras* succession. In East Greenland, Birkelund & Callomon (1985, fig. 5) recognised two other horizons below the horizon of *Rasenia cymodoce* ('17'), namely the '*Pachypictonia*' horizon ('16') and the *Rasenia inconstans* horizon ('15'). These horizons of the lower *R. cymodoce* Zone were considered to be equivalent to the *P. altenense* horizon (C1; Hantzperque 1989); they are probably equivalent to the lower *Ataxioceras hippolytense* Subzone of the lower *Ataxioceras hypselocyclum* Zone of south-east France, whereas the *R. cymodoce* horizon perhaps has its equivalents in the upper part of this subzone.

In the middle and upper part of the *R. cymodoce* Zone, only a few possibilities remain for far-reaching correlations in Europe, such as the *Eurasenia aulnisa* horizon (C5), which contains the highly characteristic Submediterranean subzonal index *A. lothari*, and the *Semirasenia askepta* horizon (C7), which has been found in Scotland, England, Normandy, western France (Birkelund & Callomon 1985; Hantzpergue 1989) and southern Germany (Heller 1964; Doben & Heller 1968). In northern Germany, Submediterranean ammonites of Early Kimmeridgian age have been found in sediments which had earlier been attributed to the Upper Oxfordian (Fischer 1991).

Substages

The Kimmeridgian Stage has been subdivided into two or three substages; here a subdivision into three substages is preferred. If the Middle Kimmeridgian is not recognised, then the middle and the upper part are united as Upper Kimmeridgian (Fig. 4).

Zones

In the Mediterranean and Submediterranean provinces, the Lower Kimmeridgian consists of three zones, which can be correlated approximately as follows: (1) *Sowerbyceras silenum – Sutneria platynota,* (2) *Ataxioceras hypselocyclum – Taramelliceras strombecki* and (3) *Crussoliceras divisum – Mesosimoceras herbichi* (Fig. 4). Their further subdivision into subzones is different in both areas (Fig. 4); precise correlation of these units is thus difficult (Pavia *et al.* 1987; Sarti 1993). Detailed subdivisions into subzones and faunal horizons have been proposed in south-east and western France (Atrops 1982; Hantzpergue 1989); that of south-east France can also be used with some minor changes in southern Germany. The Submediterranean zonal subdivision as established by Geyer (1961) can be used from the Iberian Peninsula to Bulgaria and Turkey (Sapunov 1977a; Lopez Marques 1983; Alkaya 1992). In Poland, the Submediterranean zonal subdivision has been adopted by Malinowska (1988) and Matyja & Wierzbowski (1998). In Subboreal and Boreal regions, subdivision into two zones is typical (see above): (1) *Pictonia baylei* and (2) *Rasenia cymodoce*. These zones can be replaced by the *Amoeboceras kitchini* Zone in areas where no perisphinctids occur (e.g. Wierzbowski & Smelror 1993); this zone may extend into the lower part of the *Aulacostephanus mutabilis* Zone (see below).

The Middle and Upper Kimmeridgian Substages together consist of three zones in all parts of Europe (Fig. 4).

1. In Mediterranean and Submediterranean Europe: (1) *Aspidoceras acanthicum* Zone, (2*) Mesosimoceras cavouri* or *Aulacostephanus eudoxus* Zone and (3) *Hybonoticeras pressulum/H. beckeri* or *H. beckeri* Zone.

2. In Boreal and Subboreal Europe: (1) *Aulacostephanus mutabilis* Zone, (2) *A. eudoxus* Zone and (3) *A. autissiodorensis* Zone.

In regions where no perisphinctids are present, these latter zones can be replaced in the lowermost parts by the *Amoeboceras kitchini* Zone (see above) followed by the *A. kochi, A. elegans* and *Suboxydiscites taimyrensis* Zones (Fig. 4). The latter index has been taken from northern Siberia charts (Birkelund & Callomon 1985), but there is no mention of this species in more western regions, with the exception of a determination from the Middle Kimmeridgian of Greenland. Therefore, for these Boreal regions too, *Aulacostephanus autissiodorensis* seems to represent the more appropriate index species.

The Middle Kimmeridgian zonal and subzonal subdivisions can be applied without great difficulty in Boreal, Subboreal and Submediterranean Europe, as there are large regions with overlapping guide fossils, whereas in the Mediterranean province, only a zonal subdivision is possible. Hantzpergue (1989) established a detailed subdivision in western France, which can also be used in northern France (Geyssant *et al.* 1993; Proust *et al.* 1993) and traced as far as Germany (Zeiss 1991b; Schweigert 1993a, 1996a), England, Norway and East Greenland (Hantzpergue 1989).

An unresolved problem is the lower boundary of the *A. mutabilis* Zone; it is drawn at the base of the *A. lineatum* horizon in western and northern France (Hantzpergue 1989; Hantzpergue *et al.* 1997), but in England, following the revisions of Birkelund *et al.* (1983), it is placed four horizons deeper, at the base of the *S. askepta* horizon. Recent investigations in central Poland came to similar results (Matyja & Wierzbowski 1998); these workers traced the boundary to a slightly deeper level in the upper *A. hypselocylum* Zone. In Germany and the Submediterranean region, the usage from south-east France has been followed (Hantzpergue 1989; Hantzpergue *et al.* 1991; Zeiss 1991b), which facilitates correlation with the base of the *A. acanthicum* Zone; the lower boundary of this zone in Germany is traditionally drawn at the incoming of the first representatives of the genus *Aulacostephanus* (*lineatum* group). In a recent publication by Hantzpergue *et al.* (1997), the problems of this boundary are well illustrated by their table 12; in the 'Biome Franco-germanique', the lower boundary of the *A. mutabilis* Zone is drawn below its lowermost horizon (*linealis* horizon), whereas the base of the *A. mutabilis* Subzone, curiously, is placed two horizons higher (*attenuatus* horizon). It is evident that the new data from Poland (Matyja & Wierzbowski 1998), which place the base of the *A. mutabilis* Zone much deeper, will probably necessitate revision of all these correlations.

Amoeboceras subdivisions are important from Norway to Spitsbergen (Wierzbowski 1989; Wierzbowski & Århus 1990; Wierzbowski & Smelror 1993) and East Greenland (Birkelund & Callomon 1985).

In the Upper Kimmeridgian (upper *A. autissiodorensis* Zone) of Poland and the Russian platform, a *Sarmatisphinctes fallax* Subzone has been established (Mesezhnikov 1984, 1988; Kutek & Zeiss 1994, 1997). For the lower part (lower *A. autissiodorensis* Zone), the *Discosphinctiodes subborealis* Subzone is proposed; *D. subborealis* is a significant index fossil. In Poland, *Aulacostephanus autissiodorensis* has been found only in the lower and middle parts of the *S. fallax* Subzone. In western Siberia, a zone of *Virgataxioceras dividuum* is the equivalent of the *S. fallax* Subzone (Mesezhnikov 1988). In northern Germany, Schweigert (1996a) stated, based on re-study of previous collections, that the *A. autissiodorensis* Zone is probably present.

In southern Germany, where subdivision into two subzones was previously adopted, new discoveries of ammonites have made it possible to organise the *H. beckeri* Zone into three subzones: (1) *Sutneria subeumela,* (2) *Virgataxioceras setatum* and (3) *Lithacoceras ulmense* (Schweigert & Zeiss 1994, 1999); further subdivision into several faunal horizons is possible (Schweigert 1996b, 1998). Furthermore, Schweigert (1993a, b, 1994) discovered ammonites in the Upper Kimmeridgian of Swabia with a Subboreal habitus, providing better correlation possibilities between the Subboreal *A. autissiodorensis* and Submediterranean *H. beckeri* Zones (see below).

For the Upper Kimmeridgian of western France, a useful subdivision has been proposed by Hantzpergue (1989), who subdivided the *A. autissiodorensis* Zone into two subzones, the *A. autissiodorensis* and the *Gravesia irius* Subzones, each with two faunal horizons. The succession in the Boulonnais area and farther north has been worked out in detail by Geyssant *et al.* (1993) and Geyssant (1994); the succession in southern England was reported by Cox & Gallois (1981), Birkelund *et al.* (1983) and Callomon & Cope (1996).

Correlation

Many difficulties are encountered in correlating zones (and subzones) of the Lower Kimmeridgian in Europe, mainly between the Submediterranean and Subboreal regions, but also between the Submediterranean and Mediterranean areas (Fig. 4). Many correlations are arbitrary and well-constrained correlation is only possible at certain levels. Such correlation possibilities in the Lower Kimmeridgian Substage have already been explained in connection with the problems of the Oxfordian–Kimmeridgian boundary.

Some problems exist around the Lower–Middle Kimmeridgian boundary, as the base of the *A. mutabilis* Zone is variably defined in different parts of Europe (see above). Considering the most recent results from Poland (Matyja & Wierzbowski 1998), the lower boundary of the Subboreal *A. mutabilis* Zone lies within the uppermost part of the Submediterranean *A. hypselocyclum* Zone, i.e. one zone deeper than previously assumed.

In the Middle Kimmeridgian Substage, correlations within the *A. acanthicum/A. mutabilis* Zones and the *A. eudoxus* Zone pose no great problems although the uppermost part of the *A. eudoxus* Zone of western France (*A. contejeani* Subzone) seems to correspond to the lower part of the *H. beckeri* Zone in south Germany (Schweigert 1993b). Correlation of the *A. kochi* Zone with the upper part of the *A. mutabilis* and/or the lower part of the *A. eudoxus* Zone (Wierzbowski & Smelror 1993) is still tentative, as is the correlation of the *A. elegans* Zone with most of the *A. eudoxus* Zone.

Correlation of the Upper Kimmeridgian Substage (Submediterranean *H. beckeri* Zone with the Subboreal *A. autissiodorensis* Zone) was hitherto only possible by indirect arguments. The elaboration of a new zonal and subzonal subdivision in western France by Hantzpergue (1989) and the new discoveries by Schweigert (1993a, b, 1994) in Germany and by Kutek & Zeiss (1997) in Poland now permit correlation of parts of the Upper Kimmeridgian of western, central and eastern Europe and perhaps also western Siberia.

Chronometric data

The duration of the Kimmeridgian Stage has been estimated to be 3.4 Ma (Gradstein *et al.* 1995; Ogg 1995; Ogg & Gutowski 1996); for precise data, see Figure 4.

Tithonian and Volgian (Fig. 5)

The Tithonian, and its Boreal equivalent the Volgian, have been confirmed as stage names by a vote of the International Subcommission on Jurassic stratigraphy in 1990 (Zeiss 1991a). A further stage name 'Bononien' (for the 'Upper Kimmeridgian *sensu anglico*', proposed by Cope 1993) seems unnecessary and could result in each region with a differing zonal subdivision claiming its own stage name, leading only to more confusion rather than to international agreement concerning uniform nomenclature. Furthermore, due to the different meanings of the stage 'Portlandian' in different

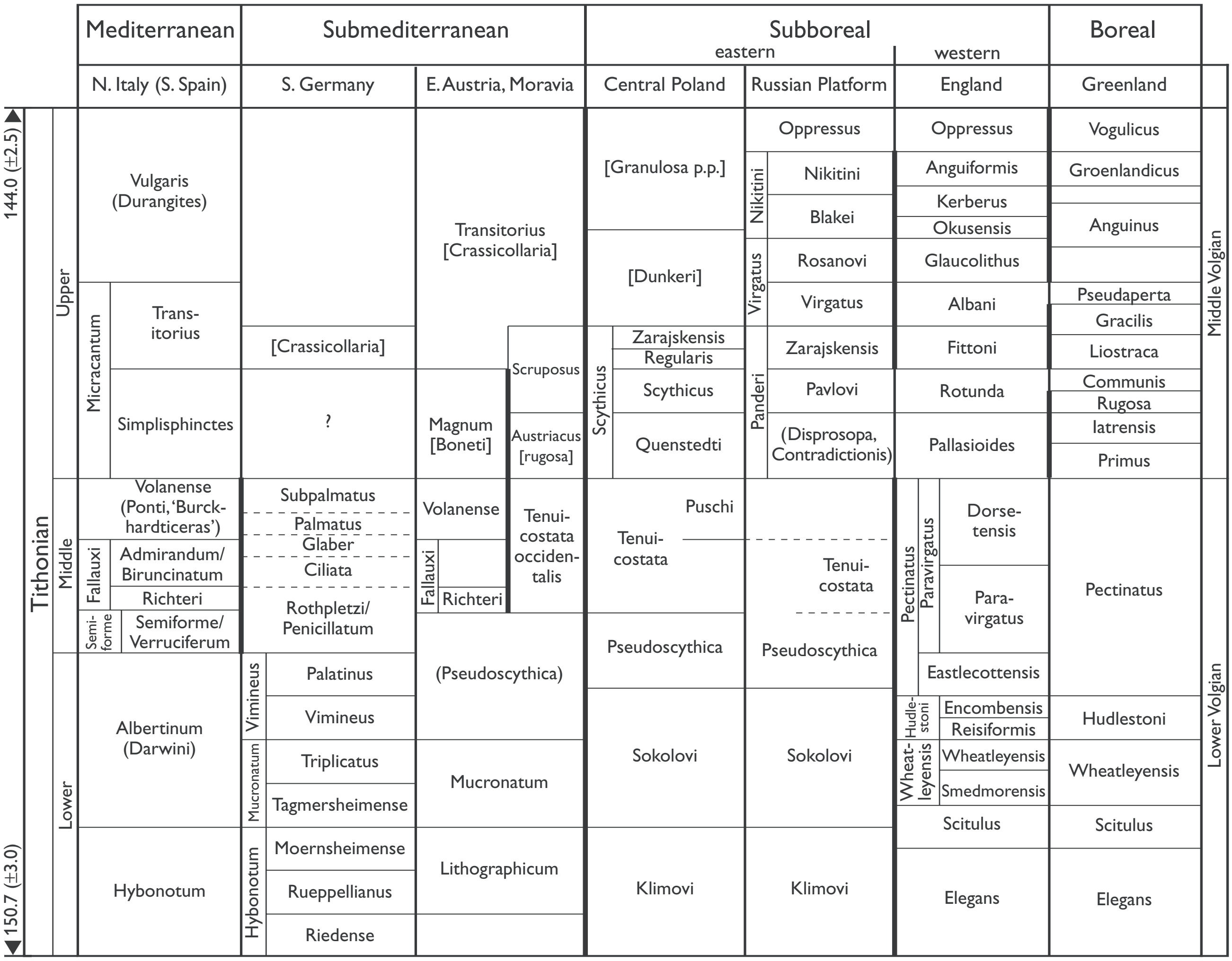

Fig. 5. A tentative correlation chart for the Tithonian and Volgian Stages in Europe (**thick** lines as in Fig. 2). Modified after Barthel (1964), Zeiss (1968, 2001), Cope *et al.* (1980), Callomon & Birkelund (1982), Kutek & Zeiss (1988, 1997), Mesezhnikov (1988), Sarti (1988), Zeiss & Bachmayer (1989), Mitta (1993), Kutek (1994) and Geyssant (1997). Non-ammonite taxa are indicated in square brackets.

countries, it was voted in 1990 that usage of this name should be discontinued. The most recent review of the Tithonian Stage and its ammonites is that provided by Geyssant (1997); for the Volgian Stage and ammonite biostratigraphy, see Gerasimov *et al.* (1995), Callomon & Cope (1996) and Kutek & Zeiss (1997).

Lower boundary

The base of the Tithonian Stage is defined by the base of the *Hybonoticeras hybonotum* Zone. It is generally supposed that the base of the coeval *Gravesia gigas, Virgatosphinctoides elegans* and *Ilowaiskya klimovi* Zones are drawn at approximately the same time level (see also below).

Substages

The Tithonian is subdivided into two or three substages; here preference is given to a tripartite Tithonian Stage (Fig. 5). If only two substages are used, then the lower and middle part are united as the lower substage ('Danubian'), the upper substage corresponds to the 'Ardescian' substage. Type regions for the Lower and Middle Tithonian Substages have been proposed by Barthel (1975) and Zeiss (1975). The type region for the Upper Tithonian Substage, the Ardescian, has been revised by Cecca *et al.* (1989a, b).

The subdivision of the Volgian is threefold, into lower, middle and upper substages. The lower and middle substages ('Gorodishchian') correspond roughly to the Tithonian Stage (Fig. 5), whereas the upper substage

('Kashpurian') belongs to the Cretaceous System (Sasonova & Sasonov 1979; Zeiss 1983, 1986; Sey & Kalacheva 1993a; W.A. Wimbledon in: Callomon & Cope 1996). A type section for the Volgian Stage has been proposed by Gerasimov & Mikhailov (1966).

Zones and Subzones

Whereas the two lower stages of the Upper Jurassic have two main zonal subdivisions, at least four subdivisions are necessary in the upper stage (Fig. 5). This is due to the extreme provincialism of ammonites caused by the increasing isolation of late Jurassic marine basins, which seem to have only rarely been directly connected; interbasinal migration was apparently only favoured during the lowermost zone of the stage.

The most important lower zone is that of *Hybonoticeras hybonotum*, which can be followed over long distances in Mediterranean and Submediterranean Europe (Zeiss 1968; Olóriz 1978; Sapunov 1979; Sarti 1988); in southern Germany it is possible to recognise three subzones and seven horizons in the *H. hybonotum* Zone (Schweigert & Zeiss 1999). In central Europe, the latter overlaps with the *Gravesia gigas* Zone, which has a rather wide distribution regionally in central and western Europe. During the last decades, many new discoveries have been reported and the genus *Gravesia* and the stratigraphy of the beds with *Gravesia* have been revised (Hahn 1963; Zeiss 1974; Hantzpergue 1989; Schweigert 1994, 1996a, b; Schweigert *et al.* 1996; Zeiss *et al.* 1996; Dimke & Zeiss 1997). In the Subboreal subprovince, the genus *Gravesia* is also present, but less numerous, so that other index fossils have been given priority, such as *Virgatosphinctoides elegans* in northwestern and *Ilowaiskya klimovi* in eastern Europe (Cope 1967; Cope *et al.* 1980; Kutek & Zeiss 1974, 1994, 1997; Callomon & Birkelund 1982; Mesezhnikov 1988). According to Callomon & Cope (1996), *Gravesia* cf. *gravesiana* occurs in the lower part of the *Virgatosphinctoides scitulus* Zone, thus demonstrating the correlation with the upper *H. hybonotum* Zone (containing *G. gravesiana*). In northern Germany, beds with *Gravesia gigas intermedia* are apparently the youngest beds containing Jurassic ammonites (Schweigert 1996a) and are succeeded by brackish and freshwater sediments up to the Jurassic–Cretaceous boundary. In these beds, ostracodes have proved to be the best guide fossil (Bischoff & Wolburg 1963; Schudack 1994, fig. 24), permitting subdivision of the Tithonian Stage in northwest Germany into four zones. In other areas, such as eastern England and Denmark, subdivision into nine zones is possible using ostracodes (Christensen 1988; Schudack 1994, fig. 24).

The upper zone of the Lower Tithonian in Mediterranean Europe, the zone of *Semiformiceras darwini* (or of *Virgatosimoceras albertinum*), is apparently equivalent to the *Neochetoceras mucronatum* and *Franconites vimineus* Zones (each of them with two subzones and some horizons) of Submediterranean Europe, as they have numerous faunal elements in common (Enay & Geyssant 1975; Olóriz 1978; Cecca *et al.* 1986; Sarti 1984, 1988; Cecca 1990a, b). Precise correlations have still to be worked out, however, and at present this is difficult as no subzones or even horizons have been recognised in the Tethyan realm. The Submediterranean zones have been traced from south-east France via southern Germany to Hungary as well as in Bulgaria and perhaps also Turkey (Zeiss 1968; Sapunov 1977b, 1979; Vigh 1984; Főzy 1988, 1993; Alkaya 1989; Atrops 1994; Főzy *et al.* 1994). Correlation with the Subboreal regions is only tentative and different proposals have been published (Fig. 5; Zeiss 1977; Mesezhnikov 1988; Kutek & Zeiss 1997).

In Subboreal Europe, the situation is not much better and correlations between the different subprovinces of Northwest and eastern Europe are only approximate. Consequently, different zonal subdivisions are also applied in these subprovinces. In eastern Europe, for example, species of the genus *Ilowaiskya* are used (e.g. the *Ilowaiskya sokolovi* and *I. pseudoscythica* Zones; Mesezhnikov 1988; Kutek & Zeiss 1997), whereas in Northwest Europe, representatives of the genera *Virgatosphinctoides, Arkellites* and *Pectinatites* have been selected (e.g. the *Virgatosphinctoides scitulus, W. wheatleyensis, Arkellites hudlestoni* and *Pectinatites pectinatus* Zones); each of these latter zones can be subdivided into two subzones (Cope *et al.* 1980; Callomon & Birkelund 1982; Geyssant 1997).

For the Middle Tithonian Substage, the subdivisions in Mediterranean and Submediterranean Europe are rather distinct (Fig. 5). Furthermore, minor faunal differentiations exist within the Mediterranean area, and different zonal indexes are used for the same time interval (Enay & Geyssant 1975; Olóriz 1978; Cecca & Santantonio 1988; Sarti 1988): (1) *Semiformiceras semiforme* or *Haploceras verruciferum*, (2) *Semiformiceras fallauxi* or (2a) *Richteria richteri* and (2b) *Simoceras admirandum/biruncinatum* (or *S. biruncinatum*), and (3) *Simoceras volanense* or '*Burckhardticeras*' *peroni* or *Micracanthoceras ponti*. Note that *Burckhardticeras* Olóriz 1978 is a junior homonym of *Burckhardticeras*

Flores Lopez 1967 (Schweigert & Zeiss 1998). In the Submediterranean area of southern Germany, the following guiding ammonites have been observed (Barthel 1975; Zeiss 1986): (1) *Virgatosimoceras rothpletzi* and *Sublithacoceras penicillatum*, (2) *Lemencia ciliata,* (3a) *Sublithacoceras(?) glaber,* (3b) *Isterites palmatus*, and (3c) *Isterites subpalmatus*. According to Scherzinger & Schweigert (1999), a horizon with *Sublithacoceras callodiscus* has been observed above the level with *Lemencia ciliata*.

In eastern Europe, the equivalents of the Middle Tithonian Substage are probably the upper part of the Lower Volgian (upper *Ilowaiskya pseudoscythica* and *Ilowaiskya tenuicostata* Zones). The latter unit is discernable in Poland but has not been recognised in Russia to date (Kutek & Zeiss 1974, 1988, 1994, 1997; Mesezhnikov 1988; Kutek 1994). In its upper part, the *Pseudovirgatites puschi* horizon is important due to its mixed fauna (Kutek & Zeiss 1974, 1988, 1997). A local time equivalent in north-eastern Austria is probably the *Isterites austriacus* Zone with *Buchia rugosa* as an important guide fossil (Fig. 5). A quite different zonal subdivision exists in Great Britain and the adjoining Subboreal and Boreal regions as far as Greenland (Cope 1978, 1980; Wimbledon 1980; Callomon & Birkelund 1982; Kejsi *et al.* 1988); the Middle Tithonian perhaps corresponds to the main part of the *Pectinatites pectinatus* Zone and perhaps to the *Pavlovia pallasioides* Zone of England or to the *Dorsoplanites primus* and *Pavlovia iatrensis* Zone of East Greenland.

The Upper Tithonian Substage consists of two or three zones in the Mediterranean area. In southern Spain, the lowermost zone has been identified as the *Simplisphinctes* Zone (Tavera 1985). This unit has not been identified in northern Italy (Sarti 1988), but could be recognised as far as north-eastern Austria, where the same ammonite fauna (containing the genus *Oloriziceras*) occurs (Zeiss & Bachmayer 1989). In the absence of the rather peculiar index genus *Simplisphinctes*, this zone was called the *Oloriziceras magnum* Zone for this region (Zeiss 2001). Above the *Simplisphinctes* (or *S. abnormis* or *O. magnum*) Zone, the *Paraulacosphinctes transitorius* Zone (with the first *Crassicollaria*) occurs. A *Micracanthoceras micracanthum* Zone is sometimes adopted instead of the *P. transitorius* Zone; this zone apparently also contains the equivalents of the *Simplisphinctes* (better *S. abnormis*) Zone (Enay & Geyssant 1975; Sarti 1988; Geyssant 1997). Some authors consider the *Simplisphinctes* and *P. transitorius* Zones as subzones of the *M. micracanthum* Zone (Benzaggagh & Atrops 1997; Geyssant 1997) although the former authors, based on Moroccan data, only partially substituted the *Simplisphinctes* Subzone, replacing its upper part and the *P. transitorius* Subzone by two new subzones, that of '*Micracanthoceras* (*Corongoceras*) spp.' and that of '*Moravisphinctes* spp.'. It is very important that these new subzones can be correlated rather precisely with the calpionellid subdivision; the *Chitinoidella boneti* Subzone (of the *Chitinoidella* spp. Zone) corresponds to the first two subzones. The base of the *Crassicollaria* spp. Zone (Zone A) approximately coincides with the base of the *Moravisphinctes* spp. Subzone, which corresponds to the lower part of this zone (= Subzone A1).

The *Durangites* Zone follows above the *P. transitorius* Zone. In northern Italy, this zone was named the *Durangites vulgaris* Zone by Sarti (1988); this term has also been adopted by other authors. In some countries, this zone has not been recognised; the equivalents of this zone are then apparently included in the *P. transitorius* Zone, which sometimes even includes parts of the Lower Cretaceous (e.g. Sapunov 1977b). The fauna of this zone has been mainly described by Tavera (1985), Tavera *et al.* (1994) and Enay *et al.* (1998a, b).

During the Middle Volgian, central Poland belonged to the eastern Subboreal subprovince, but only the lowermost unit, the *Zaraiskites scythicus* Zone (with the lower *Z. scythicus* and upper *Z. zarajskensis* Subzones) is represented (Kutek 1994). Brackish sediments prevail higher in the Polish section and yield ostracodes; the *Cypridea dunkeri* and the *Cypridea granulosa* Zones can be recognised. On the Russian Platform, the lowermost horizon of the *Z. scythicus* Subzone (*Z. quenstedti* horizon in Poland) is probably represented by beds containing *Zaraiskites disprosopa* and *Isterites*(?) *contradictionis* (Ilovaiskij & Florenskij 1941).

On the Russian Platform, a *Dorsoplanites panderi* Zone is now used instead of the *Z. scythicus* Zone (Mesezhnikov 1988; Kutek 1994); above follows the *Virgatites virgatus* Zone (with three subzones: *V. gerasimovi, V. virgatus* and *C. ivanovi*; Gerasimov *et al.* 1995). The *V. virgatus* Zone is succeeded by the *Epivirgatites nikitini* and *Lomonossovella blakei* Zone (separated by Callomon & Birkelund (1982), and, in reverse order, by Mesezhnikov (1988) but adopted as a single zone by other Russian authors (e.g. Gerasimov *et al.* 1995)). The uppermost Middle Volgian is represented by the *Paracraspedites oppressus* Zone (Mesezhnikov 1988). In the Baltic area, Middle Volgian ammonites are rare although a few specimens from Lithuania were mentioned by Rotkytė (1976, 1987). In Scandinavia, Middle Volgian ammonites have been found in Denmark

(Birkelund & Pedersen 1980) and in Norway (Birkelund *et al.* 1978). In England and East Greenland, Dorsoplanitidae are prevalent, but in both these regions, the subdivisions are distinct; in England, *Pavlovia pallasioides, Pavlovia rotunda* and *Virgatopavlovia fittoni* characterise the lower part of the Middle Volgian whereas *Progalbanites albani* and the giants *Glaucolithites glaucolithus, Galbanites okusensis, Kerberites kerberus* and *Titanites anguiformis* characterise the upper part (Cope 1978; Wimbledon & Cope 1978). As in Russia, the uppermost zone is the *Paracraspedites oppressus* Zone (Casey 1973; Kejsi & Mesezhnikov 1986; Kejsi *et al.* 1988), but not all authors adopt this zone. In East Greenland, there are some similarities with Siberian ammonite successions, but in general the subdivision there has its own character and, with three exceptions, its distinct index species (Callomon & Birkelund 1982; Mesezhnikov 1988): *Dorsoplanites primus, Pavlovia iatrensis, Pavlovia rugosa, Pavlovia communis* and *Dorsoplanites liostracus* characterise the lower part of the Middle Volgian, whereas *Dorsoplanites gracilis, Epipallasiceras pseudapertum, Crendonites anguinus, Laugeites groenlandicus* and *Epilaugeites vogulicus* are represented in the upper part. The lower part of the Upper Volgian *Praechetaites tenuicostatus* Zone of East Greenland may correspond to the uppermost part of the Middle Volgian, the upper *Paracraspedites oppressus* Zone of England and the lower *Praechetaites exoticus* Zone (= lowermost *Craspedites okensis* Zone *sensu lato*) of northern Siberia.

Correlation

As explained above, the basal zones of the Tithonian (and Volgian) can be correlated over long distances, but correlation becomes very difficult in the higher parts of these stages. Not only is it difficult to correlate between the Boreal and Mediterranean regions, but also within these regions. Distinct lineages of ammonites were evolving throughout the area and consequently it is necessary to develop and apply different ammonite zonal subdivisions; correlation possibilities are thus only few and mostly tentative. Many attempts have been made to correlate the different zonal subdivisions of Europe (Cope & Zeiss 1964; Zeiss 1965, 1974a, 1979, 1983, 1986; Enay 1972; Enay & Geyssant 1975; Olóriz 1978; Callomon & Birkelund 1982; Jeletzky 1984, 1989; Tavera 1985; Cecca *et al.* 1986; Hoedemaker 1987, 1991; Kejsi *et al.* 1988; Kutek & Zeiss 1988, 1997; Geyssant & Enay 1991; Sey & Kalacheva 1993a; Kutek 1994; W.A. Wimbledon in: Callomon & Cope 1996; Geyssant 1997). Due to problems of provinciality, such correlation schemes are necessarily speculative and ultimately unsatisfactory. A tentative summary correlation scheme is given in Figure 5, based on developments since earlier attempts by the author (Zeiss 1983, 1986). A similar, although in detail somewhat different, correlation chart has recently been published by Hantzpergue *et al.* (1998).

Concerning the Middle and Upper Tithonian (upper Lower and Middle Volgian) Substages, a number of observations are pertinent. Although correlation between the Mediterranean and Submediterranean area is quite possible in the lowermost Middle Tithonian Substage (*S. semiforme/R. richteri – V. rothpletzi/S. pennicilatum* Zones), a number of different proposals have been made for the higher zones (Enay & Geyssant 1975; Olóriz 1978; Jeletzky 1984, 1989; Cecca *et al.* 1986; Kutek 1994). A satisfactory answer to this problem requires complete revision of the famous Submediterranean Neuburg fauna and sections, in which some levels with distinct ammonite faunas have already been recognised by Barthel (1964, 1975).

In eastern central Europe (north-eastern Austria, Moravia, central and southern Poland), some Submediterranean and Mediterranean ammonites genera of Middle and Late Tithonian age are represented by characteristic forms. They sometimes interfinger with Subboreal elements, thus providing good potential for correlation (Kutek & Wierzbowski 1986; Kutek & Zeiss 1988, 1997; Kutek 1994). The *I. tenuicostata* and *Z. scythicus* Zones of central and southern Poland, for example, display interesting forms with affinities to both the Submediterranean and Subboreal provinces. Combined with observations from other localities, this facilitates better correlation between these two regions: (1) the *Pseuvirgatites puschi* horizon of the uppermost *Ilowaiskya tenuicostata* Zone contains *Isterites* species described from the higher parts of the Neuburg beds, i.e. of late Middle Tithonian age, and (2) the *Z. regularis* horizon of the lower *Z. zarajskensis* Subzone (upper *Z. scythicus* Zone) contains *Pseudovirgatites scruposus* and calpionellids indicative of the *calpionellid* Zone A, such that correlation is possible with the lower part of the *Paraulacosphinctes transitorius* Zone.

In the Boreal and Subboreal provinces, quite different zonal subdivisions exist, mainly based on different perisphinctid groups, such as the Pectinatitinae and Dorsoplanitinae in England, Denmark, Norway and Greenland and the Ilowaiskyinae, Virgatitinae and Dorsoplanitinae in Poland and Russia. The correlation of these zones is rather arbitrary, as demonstrated by Callomon & Birkelund (1982), Mesezhnikov (1988) and

W.A. Wimbledon (in: Callomon & Cope 1996), and is based mainly on similar, but non-identical species of Dorsoplanitinae.

Chronometric data

The approximate duration of the Tithonian has been estimated to be 6.7 Ma (Gradstein *et al.* 1995; Ogg 1995); for precise data, see Figure 5.

Biochronological importance of non-ammonite fossil groups: a review

The Jurassic System is the classic one for subdivision by ammonites. This fossil group has been used with much success since the pioneering work in the last century by workers such as L. von Buch, A. d'Orbigny, A. Oppel, F.A. Quenstedt, K.A. von Zittel and S. Buckman. Indeed, this contribution on the chronological subdivision of the Upper Jurassic of Europe has been compiled primarily using ammonites (see above). However, Upper Jurassic marine sediments of epicontinental shelves, the habitat of ammonites, are not present everywhere in Europe, so that ammonites are not always available. It is often necessary, therefore, to utilise other fossil groups with proven stratigraphic value such as bivalves, brachiopods, foraminifera, ostracodes and distinct plant mega-, micro- and nannofossil groups. Radiolarians, calpionellids, conchostracans, insects and vertebrates should also be added to this list; the first two groups are very useful in pelagic sedimentary basins whereas the last ones are used with much success in the stratigraphic subdivision of continental sediments, such as those of central and eastern Asia and of North America.

The challenging task of correlating between the different fossil subdivision schemes has been addressed for individual groups (e.g. Le Hégarat & Remane 1968; Surlyk & Zakharov 1982). Multidisciplinary correlation charts, typically for microfossil groups, have only been successfully developed within the last two decades. Useful though incomplete examples of such schemes, including micro- and macrofossils, have recently been published by Tavera *et al.* (1994), R. Enay (in: Cariou & Hantzpergue 1997), Gramann *et al.* (1997) and Remane (1997). It remains as one of the more important tasks, however, to establish European multidisciplinary correlation charts that incorporate all fossil groups important for biochronology and also include radiometric ages and palaeomagnetic reversal data. During the editorial work, it was brought to the attention of the author that charts fulfilling many of these expectations have recently been published by Hardenbol *et al.* (1998, charts 6–7); of special interest are the chronometric data for most of the biochronostratigraphic units (see below).

Invertebrate megafossil groups

Cephalopods – other than ammonite conchs

Aptychi

In the Tethyan regions, aptychi have proven to be a useful addition to ammonites for the subdivision of Upper Jurassic sediments. Following the studies of Durand & Gąsiorowski (1970) and Gąsiorowski (1962, 1985), it is possible to differentiate eleven zones of aptychi using four larger groups of aptychi, the lamellaptychi and laevaptychi and to a lesser degree the laevilamellaptychi and punctaptychi. Correlation between aptychi and ammonite zones still poses problems (A. Wierzbowski, personal communication 1998). Eliáš *et al.* (1996) also used aptychi ranges for biostratigraphy, but without a zonal subdivision; they preferred a multidisciplinary correlation method using the calpionellid subdivision as reference.

Belemnites

The most recent review of this fossil group is that of Doyle & Bennett (1995) which includes a section on Middle and Upper Jurassic belemnite groups, including those of Europe. This publication presents a comprehensive review of the subject, including the work of Saks & Nalnyaeva (1964, 1966), Riegraf (1980, 1981), Combémorel & Mariotti (1986), and Doyle & Kelly (1988); a range chart of the most useful taxa for biostratigraphy of the Middle and Upper Jurassic is included by Doyle & Bennett (1995). The stratigraphic ranges of some more important Polish species have been published by Pugazewska (1988) and Malinowska (1997) and those of Sicily by Combémorel & Mariotti (1990). Recently, Combémorel (1997) compiled all data available for the Tethys and the Boreal region of Europe and for each of them presented a correlation scheme with the subdivisions based on ammonites and belemnites; see also Hardenbol *et al.* (1998, chart 7).

Bivalves

The most important group of bivalves for biostratigraphic purposes in the Upper Jurassic of Europe is the genus *Buchia*. In the Boreal regions of Eurasia and North America, it is of particular importance as a supplement to ammonites. The genus has been the focus of many papers in the last decades such as Zakharov (1981, 1987, 1990), Surlyk & Zakharov (1982), Jeletzky (1984), Kelli (1990), Sey & Kalacheva (1993b) and Sha & Fürsich (1994). An interesting interpretation of the different ranges of *Buchia* species in America and Eurasia has been presented by Hoedemaker (1987). Stratigraphic range lists of selected bivalve species from Poland have been published by Karczewski & Pugaczewska (1988) and Malinowska (1997).

A correlation chart that is mainly based on buchiid bivalves but also includes other bivalve genera (e.g. *Retroceramus*) has been compiled for northern Russia and the circum-Pacific regions by Damborenea *et al.* (1992). In the Upper Jurassic, the stratigraphic resolution of bivalve taxa, with the exception of buchiids, seems to be rather limited and/or needs further research (Damborena *et al.* 1992). For some regions, stratigraphic range lists of selected bivalve species have been published, for example for Poland (Malinowska 1997; Karczewski & Pugaczewska 1998) and for northern Germany by Kaever *et al.* (1976).

Gastropods

The biostratigraphic resolution of this group in the Jurassic is not very high, but in special cases, when other guide fossils are not present, some representatives of the group may be used. An example from the Upper Jurassic of France (Nerineaceae) has been published recently by Barker (1994). Range lists of selected species from Poland have been published by Karczewski (1988) and Malinowska (1997).

Brachiopods

The most recent reviews of this group with respect to Upper Jurassic brachiopods are those of Ager (1994) and Alméras *et al.* (1991, 1994), especially for France and Britain, and Boullier & Laurin (1997) for the Tethys and the 'Domaine NW européen français'. Ager (1994) considered the group within a global context. Alméras *et al.* (1994) discussed the facies dependence of brachiopods, concluding that distinct zonal species of brachiopods are often necessary for different facies. For biostratigraphical purposes, it is possible to subdivide the Upper Jurassic of England and north-west France into nine zones and some subunits. The Polish species have been figured and described by Barczyk (1988); range charts are given in Malinowska (1997). Prozorovskaja (1993) presented an overview of the brachiopod subdivision of the Upper Jurassic of the southern part of the former USSR.

Echinoderms

To date, there is no subdivision scheme of the Upper Jurassic with respect to echinoderms. Some genera have biostratigraphic value; *Saccocoma,* for example, has been used in some multidisciplinary schemes. Thierry *et al.* (1997) presented range charts of the Upper Jurassic regular and irregular echinoid genera and species of France, with the expectation that with detailed research it would be possible to create a subdivision scheme comparable to that developed for the brachiopods of France.

Corals (scleractinians)

This group has poor biostratigraphic resolution. Its usefulness for stratigraphic purposes is therefore rather limited, also because of the close dependence of corals on ecological factors (Rosendahl 1988). Nevertheless, Beauvais (1988) subdivided the Upper Jurassic Series (except the Lower Oxfordian) into six zones based on madreporians (scleractinians). Polish species with range charts have been presented by Roniewicz & Morycowa (1988) and range charts were published by Malinowska (1997).

Sponges

This fossil group is poorly suited to regional correlation, but some species may be useful for local subdivision; examples from France have been presented by Gaillard (1997).

Vertebrate megafossils

Jurassic vertebrate fossils are too scarce to be used as guide fossils. Nevertheless, if vertebrate remains are studied thoroughly, they frequently provide valuable biostratigraphic information (e.g. elasmobranchian teeth, Gramann *et al.* 1997). It should be mentioned that the Jurassic Period in Europe saw the early evolution of mammals, the flourishing of the first true birds and the first wave of the acme of the dinosaurs.

In other parts of the globe, vertebrates have been used for stratigraphy; in North America, for example, Turner & Peterson (1998) subdivided the Upper Jurassic Morrison Formation into four biozones on the basis of dinosaurs, whereas in China, fish are used for subdivision (Chen 1990).

Invertebrate microfossils

Foraminifera

In the 1950–60s, foraminifera were one of the most important microfossil groups, together with ostracodes, for relative age determinations of marine sediments in boreholes; their importance has decreased in more recent times. Studies of foraminifera faunas from outcrops in southern Germany were reviewed by Groiss (1984). An account of epistominian zonation was given by Ascoli (1988), who also presented zonations and correlations between east Canadian offshore wells and the East European Platform (Grigelis & Ascoli 1995). Foraminifera from northern Germany were presented by Klingler *et al.* (1962) and Gramann *et al.* (1997). The guide fossils and characteristic species of the Upper Jurassic foraminifera of Poland have been published by Bielecka (1988) and Styk (1997), those of the Russian Platform by A.Y. Azbel (in: Mesezhnikov 1989). Foraminifera of Sweden were studied by Norling (1972) and Guy-Ohlson & Norling (1988). A short compilation of Upper Jurassic foraminifera in Britain has been published by Shipp & Murray (1981), together with a range chart and figures of index species. The most recent reviews of foraminifera of Europe have been compiled by Ruget & Nicollin (1997) on the small benthic forms, and by Bassoulet (1997a) on the large forms; see also Hardenbol *et al.* (1998, chart 7).

Radiolaria

This microfossil group, which has been the subject of much scientific research in recent years in Europe, is of particular importance in the Tethyan region. A comprehensive monograph was recently published by Baumgartner *et al.* (1995) on the radiolarians of the Tethys, including a catalogue of all Tethyan species. The biochronological potential for subdividing the Upper Jurassic Series into 'Unitary Association Zones' (U.A.Z.) is well-demonstrated; there are six such zones covering the whole Upper Jurassic. They have a duration of between 2–6 Ma. This monograph demonstrates the significant advances in research into this group, especially if new quantitative concepts, such as the 'Unitary Association Zones', are applied to the biochronological subdivision of the Upper Jurassic.

Research into radiolarians and their stratigraphic potential has also been on the increase outside the Tethys, as demonstrated by recent publications concerning the Submediterranean province (Riegraf 1987; Kießling 1997; Zügel 1997; Zügel *et al.* 1998), and even the Subboreal and Boreal provinces, including the North Sea (Dyer & Copestake 1989), the Russian Platform and the Barents Sea (Vishnevskaya 1993, 1997, 1998; Kozlova 1994). Dyer & Copestake (1989) introduced a biozonation based on a succession of ten radiolarian events in the Kimmeridgian and Tithonian. Important attempts are also underway to correlate the new peri-Tethyan radiolarian assemblages with different micro- and macrofossil biozonations (Vishnevskaya & De Wever 1997); owing to strong provincialism, direct correlation between the peri-Tethyan and Tethyan zonations is still very difficult, but has been undertaken recently (Hardenbol *et al.* 1998, chart 7).

Ciliata

This group is important only in the Tethyan region and the surrounding shelf deposits; the most comprehensive studies of the ciliata in recent years have been published as a result of the Sümeg meeting (Fülöp 1986; Remane *et al.* 1986). Polish forms have been reported by Nowak (1988) and those of Spain by Tavera *et al.* (1994) and Olóriz *et al.* (1995). Remane (1997, 1998) recently published informative reviews of the state-of-the-art of the group, providing tables which include the stratigraphic succession of calpionellid species and the correlation of calpionellid, nannofossil and ammonite subdivisions with magnetostratigraphic events. Nearly simultaneously, Blau & Grün (1997a, b) and Grün & Blau (1996, 1997) proposed a revision of the calpionellid zonal and subzonal division. For the Tithonian Stage, they introduced and formally defined two zones and seven subzones; the duration of zones in the Jurassic is less than one million years, that of subzones about 300 000 years.

Important results from the southern Tethyan margin have been contributed by Benzaggagh & Atrops (1995, 1997). These workers provided precise correlation and species range charts for ammonites and calpionellids for the lower part of the calpionellid succession, which previously was poorly known, and clarified the succession of zones and subzones from the Middle Tithonian *Semiformiceras fallauxi/Chitinoidella dobeni* Subzone to the Upper Tithonian *Durangites vulgaris/Crassicollaria* A3 Subzone. An important contribution on the calpionellid faunas of the southern and eastern Tethyan region of Europe was presented by Reháková & Michalík (1997); the western Carpathians and their foreland in Moravia were treated by Řehánek (1990) and Reháková (1995, 2000). In all these last-mentioned publications, the Middle/Upper Tithonian boundary has apparently been drawn a little too high. Following the results of Benzaggagh & Atrops (1995, 1997), this boundary lies between the Dobeni and Boneti Subzones of the Chitinoidella Zone and not above this zone.

Ostracodes

This group has a rather high stratigraphic resolution and has therefore been used frequently and successfully for the subdivision of sediments in northern Germany, Poland, England, the Netherlands, the North Sea Basin, France and Russia. In a recent monograph, Schudack (1994) revised the ostracodes of the Upper Jurassic in north-west Germany, documenting the correlation possibilities of this group in western, central and northern Europe. The Upper Jurassic of north-west Germany was subdivided into nineteen ostracode zones, representing variable durations (0.25–2.5 Ma; Schudack 1996a; Gramann *et al.* 1997). This study also presents a comprehensive list of all important publications on ostracodes. In northern Europe, the papers of Herngreen *et al.* (1988), Herngreen & Wang (1989) and Guy-Ohlson & Norling (1994) deal with this group in the Netherlands and Sweden, respectively. In Poland, Bielecka *et al.* (1988) treated the group, and range charts have been published by J. Szteijn (in: Marek & Pajchlova 1997); Danish faunas were described by Christensen (1988). The most recent reviews of European ostracodes are those of Bodergat (1997) on marine ostracodes and Colin (1997) on non-marine ostracodes; see also Hardenbol *et al.* (1998, chart 7).

Plant microfossils

Dinoflagellata

Dinoflagellate cysts have become a widely used supplement to ammonites and are of particular importance in the subsurface. In a recent study, Poulsen (1996) emphasised the important role of dinoflagellates in Jurassic stratigraphy while comparing the Upper Jurassic of Denmark and Poland. The marine Upper Jurassic of Denmark was divided into seven zones and fifteen subzones whereas that of Poland was divided into four zones and twelve subzones (Poulsen 1996); the dinoflagellate cyst zonation of the Jurassic of Subboreal Europe is reviewed in Poulsen & Riding (2003, this volume). In Great Britain, Riding & Thomas (1992) have delivered the most recent compilation of dinoflagellates. Other important papers are those of Sarjeant (1979), Riley (1980), Riley & Fenton (1982) and Riding & Sarjeant (1984); one concerning Russia is that of Lentin & Vozzhennikova (1990). In the Netherlands, Herngreen *et al.* (1988; see also Herngreen & Wang 1989) presented a report on the stratigraphic bioevents based on the first and last appearance of dinoflagellate cyst species which made possible a subdivision into nine zones. In north-west Germany, the Oxfordian and Kimmeridgian has been subdivided into three dinoflagellate zones and eight subzones (Gramann *et al.* 1997). Detailed subdivisions for the Boreal and Tethyan regions have recently been published by Hardenbol *et al.* (1998, chart 7).

Calcareous nannofossils (coccoliths, nannolith groups)

Recent advances in Jurassic calcareous nannofossil research have been reviewed by Bowen (1996), who dealt with several general aspects of this group, such as evolutionary succession, species diversity and longevity, distribution and provincialism, which are all important when regarding the utility of the group for biostratigraphic purposes. If conditions are favourable, then it is possible to subdivide the Upper Jurassic into five Boreal nannofossil zones (with six subzones) or three Submediterranean nannofossil zones (with seven subzones); correlation between these two regions is thus still problematic. The calcareous nannofossil bioevents were recently reviewed by Gardin (1997). Subdivisions and correlations for the Boreal/Subboreal and the Tethyan/Submediterranean Provinces can be found in Hardenbol *et al.* (1998, chart 7).

Charophyaceae

This group of calcareous algae has received new impetus with respect to its potential for biostratigraphy. In a recent publication, the results of a local zonal subdivision based on charophytes in the Lower Saxony Basin of north-west Germany (Schudack 1996b) has been correlated firstly with the new European Mesozoic charophyte biozonation (Riveline *et al.* 1996), secondly with the subdivisions of other microfossil groups in north-west Germany, such as ostracodes and dinocysts, and thirdly with the old micropalaeontological subdivisions for the Upper Jurassic (Malm) of north-west Germany (e.g. Klingler *et al.* 1962; Wick & Wolburg 1962). In north-west Germany, from the Upper Oxfordian to the top of the Tithonian, five charophyte zones are now recognised, whereas in other parts of western Europe there are only three (Schudack 1991, 1993). The stratigraphic resolution of this group is not very high in the Upper Jurassic. Each biozone represents a duration of between 0.5 and over 2 million years. The Charophyaceae of western Europe have been revised in detail by Schudack (1993), and a useful compilation of all new data in Europe has been compiled by Riveline *et al.* (1996); see also Hardenbol *et al.* (1998, chart 7).

Dasycladaceae

This group seems to be only locally important for biostratigraphy (e.g. Portugal, Italy, Dinarids); a short review was presented by Bassoulet (1997b).

Spores and pollen

The value of pollen and spore grains for stratigraphic subdivision is not very high in the Upper Jurassic. The palynostratigraphy of Sweden (north-west Skåne) was discussed by Guy-Ohlson & Norling (1988) in connection with a study of the microflora of some boreholes. It was revealed that “detailed correlation without the presence of dinoflagellates or other significant taxa appears difficult if not impossible” (Guy-Ohlson & Norling 1988, p. 15). In the Central Graben of the southern North Sea, Upper Jurassic sediments were subdivided into four zones on the basis of sporomorphs (Herngreen *et al.* 1988; Herngreen & Wang 1989). In north-west Germany, the Upper Jurassic was divided into four zones using spores and pollen (Gramann *et al.* 1997).

The group apparently has its greatest importance at the system boundaries; it has been used successfully at the Triassic–Jurassic boundary and, to a lesser degree, at the Jurassic–Cretaceous boundary.

Magnetostratigraphy

This important method has become more directly applicable for stratigraphic purposes in the last few decades, especially when combined with radiometric and biostratigraphic data. Some of the more important papers on this topic are: (1) Mesozoic in general, Harland *et al.* (1990), Gradstein *et al.* (1995); (2) Upper Jurassic – Lower Cretaceous, Ogg (1983), Ogg *et al.* (1984), Odin *et al.* (1994); (3) Oxfordian, Steiner *et al.* (1985), Ogg & Steiner (1988a), Ogg *et al.* (1991), Ogg & Coe (1998); (4) Oxfordian – Lower Kimmeridgian, Ogg & Gutowski (1996); (5) Kimmeridgian–Tithonian, Ogg *et al.* (1994), (6) Jurassic–Cretaceous boundary, Ogg *et. al.* 1984), Ogg & Lowrie (1986), Ogg & Steiner (1988b), Ogg *et al.* (1991, 1994). In a recent publication on sequence chronostratigraphy of European Mesozoic basins, charts with magnetochronostratigraphic units have been compiled together with sequence chronostratigraphic and biochronostratigraphic data (Hardenbol *et al.* 1998, see below); the time span of the Upper Jurassic contains polarity chronozones M35 (upper part) – M19.

Sequence chronostratigraphy

Sequence stratigraphy is gaining in importance in chronostratigraphic correlation, as illustrated recently by the presentation of a framework for the European Mesozoic and Cenozoic basins (Hardenbol *et al.* 1998). Many data have been used and compiled in charts, two of which are important for the Upper Jurassic. They demonstrate the sequence chronostratigraphy (Sequences, T-R Facies Cycles, Major Transgressive–Regressive Cycles) for the Boreal and Tethyan realms combined with the ammonite biochronostratigraphy and magnetostratigraphy, plotted against the time scale.

The Upper Jurassic of Europe starts in the upper half of the transgressive part of the Second Major T-R Cycle (1st order cycle, named North Sea Cycle) in the Jurassic and ends within the regressive phase of this cycle. A total of 21 sequences (3rd order cycles) have been recognised (Ox 0–8, Ki 1–7, Ti 1–6) and three 2nd order T-R cycles (T8b–R10b) in the Boreal area, whereas the number in the Tethyan area is somewhat lower. A detailed overview of the North Sea Cycle in Europe (from the North Sea to south-east France) has been presented by Jacquin *et al.* (1998); marginal areas have been studied as follows: East Greenland (Surlyk 1991; 2003, this volume), Portugal, Lusitanian Basin (Leinfelder & Wilson 1998), Portugal and Spain, South Iberian Margin (Olóriz *et al.* 1991), south-east France (Jan du Chêne *et al.* 2000), Switzerland (Gygi *et al.* 1998), West Carpathians (Reháková 2000) and Russia (Sahagian *et al.* 1996).

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