

Towards a consistent Oxfordian-Kimmeridgian global boundary: current state of knowledge

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Abstract: New data related to the definition of the Oxfordian/Kimmeridgian boundary obtained mostly after 2006 are discussed – *i.e.* after the proposal for the uniform boundary of the stages at the Flodigarry section at Staffin Bay on the Isle of Skye, northern Scotland has been given. This boundary is based on the Subboreal-Boreal ammonite successions – where it is distinguished at the base of the Subboreal Baylei Zone which is defined by the *Pictonia flodigarriensis* horizon, and which corresponds strictly to the base of the Boreal Bauhini Zone. This boundary is defined also by other stratigraphical data – both palaeontological, geochemical and palaeomagnetical (including its well defined position close to the boundary between magnetozones F3n, and F3r – the latter corresponding to marine magnetic anomaly M26r). The boundary and the section are thus proposed as the GSSP for the Oxfordian/Kimmeridgian boundary.

The boundary is well recognizable also in other sections of Subboreal and Boreal areas as discussed in the study, including southern England, Pomerania and Peri-Baltic Syncline, Russian Platform, Northern Central Siberia, Franz - Josef Land, Barents Sea and Norwegian Sea. The discussed boundary is recognized also in Submediterranean-Mediterranean areas of Europe and Asia where it correlates with the boundary between the Hypselum and the Bimmamatum ammonite zones. The changes in ammonite faunas at the boundary of these ammonite zones – mostly of ammonites of the families Aspidoceratidae and Oppeliidae – make possible also recognition of the boundary in question in the Tethyan and Indo-Pacific areas – such as central part of the Americas (Cuba, Mexico), southern America, and southern

parts of Asia. The climatic and environmental changes at the Oxfordian/Kimmeridgian transition discussed in the study relates mostly to the European areas. They show that very unstable environments at the end of the Oxfordian were subsequently replaced by a more stable conditions representing a generally warming trend during the earliest Kimmeridgian. The definition of the boundary between the Oxfordian and Kimmeridgian as given in the study results in its wide correlation potential and means that it can be recognized in the different marine successions of the World.

Introduction

Since the publishing of the original proposal for the recognition of the Global Stratotype Section and Point (GSSP) of the base of the Kimmeridgian Stage at the Flodigarry section, Staffin Bay, Isle of Skye, northern Scotland (Matyja *et al.*, 2006; Wierzbowski A. *et al.*, 2006) several years have passed when new data related to that boundary and its correlation potential have appeared. These new data, partly published, but partly announced only as oral presentations during scientific meetings – mostly the 8th Jurassic Congress in Sichuan, China, August 2010, the 1st International Congress on Stratigraphy, Lisbon, July 2013, the 9th Jurassic Congress in Jaipur, India, January 2014, the Meeting of the Kimmeridgian Working Group in Warsaw, Poland, May 2015, and the 2nd International Congress on Stratigraphy, Graz, July 2015 - are summarized below. This work represents the progress in knowledge since 2006 in relation to the definition of the Oxfordian/Kimmeridgian boundary, as outlined by the Convenor of the Kimmeridgian Working Group and supplemented and/or commented on by the members the Group in order to provide herein a full basis for voting and a final decision on the matter of the boundary in question.

It should be remembered that the base of the Kimmeridgian Stage as defined by Salfeld (1913) at the base of the Kimmeridge Clay Formation at Ringstead Bay, Dorset, was established on the lineage of the ammonite family Aulacostephanidae, at the level where an older genus *Ringsteadia* was replaced by a younger genus *Pictonia*. This definition produced, however, serious stratigraphical inconveniences which were related with: (1) difficulties with stratigraphical correlations being the consequence of the not very wide palaeogeographical distribution of ammonites of the family Aulacostephaniade which are considered as typical of the relatively small Subboreal Province of northern Europe, as well as their marked spatial differentiation (see *e.g.* Sykes and Callomon, 1979; Wierzbowski A., 2010 a); (2) the generally poor knowledge on the phylogenetical transition between the genera *Ringsteadia*

and *Pictonia* in the Dorset coast sections being the consequence of a stratigraphical gap at the base of the Kimmeridge Clay Formation (see e.g. Matyja *et al.*, 2006). The former item resulted in the erroneous correlation between the Subboreal succession of the NW Europe and the Submediterranean-Mediterranean successions of middle and southern Europe in the past (see Arkell, 1956, and earlier papers cited therein – especially Dieterich, 1940). In consequence, the Oxfordian/Kimmeridgian boundary has been placed at two non-isochronous levels in different areas of Europe: one at the boundary of the Pseudocordata Zone (defined by occurrence of the genus *Ringsteadia*) and the Baylei Zone (defined by occurrence of the genus *Pictonia*) in the Subboreal Province, and another at the boundary of the Planula Zone, and the Platynota Zone (or the Silenum Zone) in the Submediterranean-Mediterranean provinces. The latter as more recently indicated runs about two ammonite zones higher (and is about 1.5 Ma younger) than the Subboreal Standard (see Ogg and Hinnov, 2012; see also Schweigert and Callomon, 1997; Matyja and Wierzbowski A., 1997; Matyja *et al.*, 2006; Wierzbowski A. *et al.*, 2006; Wierzbowski A. and Matyja, 2014 a, b, and other papers cited therein). The second item resulted in generally poor knowledge of the Aulacostephanidae lineage at the transition from the genus *Ringsteadia* to the genus *Pictonia*, which appeared especially troublesome in detailed stratigraphical correlations in this stratigraphical interval, also because of an almost total absence of any other ammonites (especially of the family Cardioceratidae) in the Dorset coast sections.

Study undertaken at the Flodigarry section at Staffin Bay on the Isle of Skye, northern Scotland (Figs 1-2) showed a continuous succession of Subboreal ammonites across the Oxfordian/Kimmeridgian boundary and revealed the presence of a new assemblage of ammonites, referred to the new species *Pictonia flodigarriensis* Matyja, Wierzbowski et Wright which fills the stratigraphical gap in the ammonite succession at the boundary of the *Ringsteadia* assemblages (Pseudocordata Zone) and the *Pictonia* assemblages (Baylei Zone) in the Dorset coast. On the other hand, the section shows a continuous succession of ammonites of the family Cardioceratidae of the genus *Amoeboceras* with the older subgenus *Amoeboceras* followed successively by the subgenera *Plasmatites* [with such species as *P. praebauhini* (Salfeld), *P. bauhini* (Oppel) and *P. lineatum* (Quenstedt)] and then by the first *Amoebites* – *A. bayi* Birkelund et Callomon.

According to these new data, the Oxfordian/Kimmeridgian boundary in the Flodigarry section has been defined (Matyja *et al.*, 2006) at the base of the newly recognized horizon of *Pictonia flodigarriensis* treated as the basal horizon of the Baylei Zone and thus the base of

the Kimmeridgian. It is marked by the replacement of the Subboreal *Ringsteadia* (M) – *Microbiplices* (m) by *Pictonia* (M) – *Prorrasenia* (m). The same level is marked by the first appearance of Boreal cardioceratids of the subgenus *Plasmatites* which results independently in the correlation of the Subboreal boundary in question with the base of the Boreal Bauhini Zone (*i.e.* the boundary between the Rosenkrantzi Zone and the Bauhini Zone of the Boreal subdivision) (see Matyja *et al.*, 2006; Wierzbowski A. *et al.*, 2006). This enlarges very much the correlation potential of the proposed Oxfordian/Kimmeridgian boundary.

The ammonite stratigraphy which is the basis for recognition of the Oxfordian/Kimmeridgian boundary is based thus on the Subboreal-Boreal ammonite successions studied in the Flodigarry section, Staffin Bay, Isle of Skye (Matyja *et al.*, 2006), proposed, and accepted by the Kimmeridgian Working Group in 2007 as the primary standard (GSSP) of the boundary in question. The main problem (still not formally settled) relates to definition of the base of the Subboreal Baylei Zone – and especially the role of the *P. flodigarriensis* horizon in stratigraphical correlations. On the other hand, this zone is historically, and formally, accepted by both the Kimmeridgian W.G. and the International Subcommission on Jurassic Stratigraphy as the lowest zone of the Kimmeridgian Stage (Wierzbowski A., 2010 b).

New data from the Staffin Bay (Isle of Skye) sections

The full description of the section at Flodigarry (Isle of Skye, Staffin Bay) was presented in Wierzbowski A. *et al.* (2006) giving details on its lithological succession and ammonite biostratigraphy (after Matyja *et al.*, 2006 and earlier papers cited therein), the microfossil biostratigraphy – mostly dinoflagellates (after Riding and Thomas, 1997), and also acritarchs and other non-dinophycean marine palynomorphs (after Stancliffe, 1990), the isotope stratigraphy – especially oxygen and carbon isotopes (after Wierzbowski H., 2004, including new data of this author), and also strontium isotopes (after Jenkyns *et al.*, 2002), and the magnetostratigraphy (new data by M. Hounslow which were combined with the other data from Dorset and South Ferriby of Ogg and Coe, 1997). These data presented the general characteristics of the section which according to the opinion given (Wierzbowski A. *et al.*, 2006) fulfilled the principal criteria of Remane *et al.* (1996) for definition as a GSSP for the base of the Kimmeridgian Stage. Additional observations obtained after 2006 in the section in question are detailed below.

Ammonite biostratigraphy: Some minor changes were introduced more recently in the biostratigraphical interpretation of the section (Fig. 2) when compared with the interpretation of Matyja *et al.* (2006, fig. 3) and Wierzbowski A. *et al.* (2006, fig. 4). The oldest ammonites of the Pseudoyo Subzone of the Pseudocordata Zone of the uppermost Oxfordian illustrated in Matyja *et al.* (2006, p. 391, fig. 4a) do not belong to the species *M. microbiplex* (Quenstedt). Instead, they are rather closer to early representatives of the *M. procedens* (Oppenheimer) – *M. guebhardi* (Oppenheimer) group as shown by their fairly dense ribbing on the inner whorls and the lower point of splitting of the ribs (Wierzbowski A. and Matyja, 2014 b, p. 60). This observation together with re-interpretation of some forms which have been included previously in *Amoeboceras regulare* Spath as early representatives of *A. marstonense* Spath results in the moving of deposits originally placed in the uppermost part of the Boreal Regulare Zone into the lowest part of the Boreal Rosenkrantzi Zone (Wierzbowski A., Matyja, 2014 b, p. 61). These subtle changes in interpretation of the section occur within the uppermost Oxfordian deposits and are shown in Fig.2. They have no influence on the position of the Oxfordian/Kimmeridgian boundary as originally indicated.

Isotope stratigraphy: New records of carbon isotope variations in belemnite rostra ($\delta^{13}\text{C}_{\text{carb}}$) and terrestrial fossil wood debris ($\delta^{13}\text{C}_{\text{org}}$), as well as oxygen isotope record ($\delta^{18}\text{O}_{\text{carb}}$) from the Staffin Bay sections were published by Nunn *et al.* (2009). The results show the presence of the highest palaeotemperatures during the Oxfordian–Kimmeridgian transition (Regulare–Baylei chrons) within the whole interval from the base of the Oxfordian up to the lowest Kimmeridgian which generally confirms the earlier assumption of H. Wierzbowski (in: Wierzbowski A. *et al.* 2006). The analysis of the carbon isotope composition of both marine carbonates and terrestrial organic matter shows the presence of a gradual fall in $\delta^{13}\text{C}$ values in the Upper Oxfordian and the lowermost Kimmeridgian.

Rhenium-Osmium (^{187}Re - ^{188}Os) dating of black shales samples at Flodigarry, Staffin Bay taken from about 1.20-1.40 m below the base of bed 36, yielded an age of 154.1 (+/- 2.2) Ma at the proposed GSSP for the Oxfordian/Kimmeridgian boundary (Selby, 2007). These sampled levels correspond precisely to the base of the Kimmeridgian Stage (Pseudocordata-Baylei zone boundary placed at the base of the *Pictonia flodigarriensis* horizon of the Subboreal subdivision = Rosenkrantzi-Bauhini zone boundary of the Boreal subdivision). It is the first so precise radiometric dating of this boundary, which was assumed by Ogg and Hinnov (2012) to correlate with oceanic basalt marine anomaly M26r at 157.3 +/- 3.4Ma.

Molecular organic geochemistry: Study of the composition of the soluble organic matter at the Oxfordian/Kimmeridgian boundary in the Flodigarry section, Staffin Bay, shows the exceptional preservation and very low thermal degradation of the organic matter (Lefort *et al.*, 2012). The matter is mostly of continental origin composed mostly of the rests of coniferophytes, and its composition does not significantly change in the section. It should be remembered, however, that the bulk of the samples studied were taken from the Lower Kimmeridgian deposits, and that the lowest part of the succession studied (mostly the lower part of the Bauhini Zone) shows a lower organic terrestrial supply than the higher part of the Lower Kimmeridgian.

Magnetostratigraphy: Magnetostratigraphic study of the Flodigarry section at Staffin Bay was detailed by M.W. Hounslow and J. Ogg (in: Wierzbowski A. *et al.*, 2006, figs 7-8) who originally indicated that the uppermost Oxfordian was dominated by normal polarity, and the lowermost Kimmeridgian by reverse polarity. The data across the Oxfordian/Kimmeridgian boundary at Flodigarry was combined with magnetostratigraphic data from other U.K. sections (Przybylski *et al.*, 2010) and was interpreted as lying close to the boundary between M27n and M26r chrons of the marine magnetic anomalies sequence (M-sequence). However, the exact level for the change in polarity in the Flodigarry section was not precisely known because of a lack of samples from *ca.* 1m interval around the Oxfordian/Kimmeridgian boundary at the top of bed 35. New samples taken from that interval collected by J.K. Wright have been studied by M.W. Hounslow and M. Galvin (Hounslow *et al.*, 2015) and have been combined with the previous data, to show the magnetic polarity across this interval (Fig. 3). Ten of the new samples display reverse polarity, and six normal polarity (for 1 sample the polarity was uncertain). Like the previous study, the magnetisation components are determined using either by straight-line segments (line-fits; Fig. 3) or great circle trends towards the expected Jurassic directions. The mean geomagnetic field direction determined for the new dataset give declination, inclination of $4^{\circ}, 50^{\circ}$ ($\alpha_{95}=6.5^{\circ}$, $k=16.8$, $n=16$), giving a palaeopole at latitude, longitude of $+64^{\circ}, 166^{\circ}$, similar to that from the previous sample set based on the entire section (Przybylski *et al.*, 2010).

At Flodigarry the base of magnetozone F3n (Fig. 3) is located between 235 cm and 260 cm below the base of bed 36. This interval coincides (within the sampling resolution) with the top of the *R. pseudocordata* Subzone at 240cm below bed 36. The base of magnetozone F3r (Fig. 3) is located between 128 and 148cm below the base of bed 36, and is now well defined by detailed sampling. The base of the *P. densicostata* Subzone (FAD of *P.*

flodigarriensis) is located at 122cm below bed 36, so these two events are now closer than ~25cm from each other. Assuming that the base of F3r correlates to the base of marine magnetic anomaly M26r, and using the marine magnetic anomaly age scale in Ogg (2012), this equates to an age difference of no more than ~30kyrs. Therefore, the boundary of magnetozones F3n-F3r provides an ideal secondary marker for the base of the Kimmeridgian in the Flodigarry section.

The new data indicate that like at the South Ferriby and Black Head sections, the Evoluta Subzone is dominated by normal polarity (Fig. 4). The underlying reverse magnetozones F2r, seems to occupy the mid and upper parts of the Pseudocordata Subzone. The polarity in the older parts of the Pseudocordata Zone is only really defined at the Flodigarry sections, so remain somewhat uncertain, considering the wide sample spacing.

Conservation of the proposed Kimmeridgian GSSP at Flodigarry: A key part of the guidelines for GSSP selection of Remane *et al.* (1996) concerns its potential for continued use, including safeguarding the reference section for future scientific study, including sampling. Collectively grouped as “*Other requirements*”, these criteria effectively relate to the legal heritage status of the site and its on-going or potential sensitive management. Although national conservation systems vary widely – and can even impact negatively on ongoing scientific use of a geological locality - at Flodigarry, a combination of state ownership and a well-established and scientifically informed legal conservation framework (see Page and Wimbledon, 2006) provides an ideal scenario for the effective safeguard of the candidate GSSP for future scientific study. These criteria are addressed in turn below:

“*Permanently fixed marker*”: Despite being a natural foreshore exposure, a permanent marker could still be placed, for instance using an approved, imbedded metal marker, which could be relocated using a GPS reference and metal detector, whatever the beach conditions. This use of this type of buried marker is well established for terrestrial ecological surveys, for instance in woodland.

“*Accessibility*”: The site is readily accessible on foot along a public right of way from Flodigarry village to the shore, across which there is open public access. Examination of the boundary level requires a falling tide.

“*Free access*”: As above, public access rights are guaranteed by Scottish law.

“Guarantees from the respective authority concerning free access for research and permanent protection of the site”: The area is publically owned and managed on behalf of the Scottish Government by SGRPID (Estates Office, Portree, Isle of Skye, IV51 9DH, Scotland) and protected through the Nature Conservation (Scotland) Act 2004 within the legally designated Trotternish Ridge Site of Special Scientific Interest. Advice concerning protocols and permissions to sample should be directed to: south_highland@snh.gov.uk. For further information about the conservation of natural heritage sites in Scotland see: www.snh.gov.uk.

Position of the Oxfordian/Kimmeridgian boundary in other sections of the Subboreal and Boreal areas

Biostratigraphical correlation of the Subboreal/Boreal succession of the uppermost Oxfordian and lowermost Kimmeridgian of the Flodigarry section with other sections showing similar types of ammonite faunas in northern areas of Europe (Fig. 1) and Asia and adjoining areas of the Arctic (Fig. 8) have been the subject of several papers published recently. The main results of the studies are commented on below.

Southern England: This is the classical area of the Subboreal Province, and the ammonites occurring here are almost entirely representatives of the family Aulacostephanidae. A recent study of these Subboreal ammonites from southern England – which is their “home area” (Wright, 2010) generally shows the incompleteness of the succession at the boundary of the Oxfordian and Kimmeridgian *i.e.* at the boundary of the Pseudocordata Zone and the Baylei Zone. The *P. flodigarriensis* horizon is thus normally missing, but in some basinal sections like that of the central Wessex Basin it seems to be present, but it is normally overstepped by a younger *P. densicostata* horizon typical of the lowermost preserved deposits of the Baylei Zone (the so-called *Inconstans* Bed) – of such areas as the Dorset coast and Wiltshire (Wright, 2003). “Thus, the previously supposed local occurrence of an index species – the *Pictonia flodigarriensis*, and of the relevant horizon in northern Scotland only – used as an argument against wider recognition of the base of the *P. flodigarriensis* horizon, as a uniform base of the Oxfordian/Kimmeridgian boundary is not substantiated” (see Wierzbowski 2010 b).

Pomerania and Peri-Baltic Syneclise: The large quarries of Czarnogłowy (Zarnglaff) in western Pomerania in Poland yielded in the past ammonites of the family Aulacostephanidae described originally by Dohm (1925) and by Wilczyński (1962). The

oldest ammonite assemblage consists of representatives of the genus *Vineta* Dohm, 1925, and “*Ringsteadia*” (originally described and often cited thereafter as true representatives of this genus) – but corresponding in fact to the newly established genus *Vielunia* Wierzbowski et Główniak, 2010 (see Wierzbowski A. *et al.*, 2010). These deposits from Pomerania were traditionally correlated with the Pseudocordata Zone of the Subboreal uppermost Oxfordian (*e.g.* Arkell, 1956). However, both these groups of ammonites as indicated recently in other areas (Główniak *et al.*, 2010; Wierzbowski A. *et al.*, 2015 a) co-occur with Boreal ammonites of the subgenus *Plasmatites* indicative of the Boreal Bauhini Zone. Thus, the relevant deposits from Pomerania belong in fact to the lowermost Kimmeridgian, and may be attributed to the Jaekeli Zone (after *Vineta jaekeli* Dohm) (see Dohm, 1925; Wilczyński, 1962) corresponding to a large part of the Subboreal Baylei Zone (possibly except its topmost part).

Newly published material from boreholes in north-eastern Poland in the area of the Peri-Baltic Syncline (Wierzbowski A., *et al.*, 2015 a) include the description of a rich collection of ammonites from the Oxfordian and Lower Kimmeridgian including ammonite faunas from the stratigraphical interval at the Oxfordian and Kimmeridgian boundary. The fauna of the uppermost Oxfordian is dominated by Boreal ammonites indicative of the Rosenkrantzi Zone, but including also typical Subboreal ammonites of the Pseudocordata Zone of the genera *Ringsteadia* (M) – *Microbiplices* (m) – which show marked similarity to the coeval fauna from southern England. On the other hand, the younger fauna is dominated by Subboreal ammonites of the genera *Vielunia* (M) – *Prorasenia* (m) and *Vineta* (M,m) which may be correlated with the Baylei Zone (or Jaekeli Zone), as it co-occurs with the Boreal ammonites *Amoeboceras* (*Plasmatites*) of the Bauhini Zone. This new assemblage of Subboreal ammonites differs markedly from the coeval assemblage from southern England composed of representatives of the genera *Pictonia* (M) and *Prorasenia* (m). The differences in development of the aulacostephanid faunas during the earliest Kimmeridgian between the NW European areas and NE European areas was related to allopatric speciation within the Aulacostephanidae lineage. This resulted from the development of land-barriers separating areas of the Subboreal Province – north-western and north-eastern one- due to the uplift of the London-Brabant Massif and the Ringkøbing-Fyn High (Enay, 1980; Wierzbowski A., 2010 a).

Stratigraphical interpretation of the deposits at the Oxfordian/Kimmeridgian boundary is possible also on the basis of the microfossils which have been correlated with the ammonite subdivisions. Especially useful here are the cysts of Dinoflagellata which are commonly

recognized over wide areas from southern England, the North Sea, and areas more located towards the east - from the Danish Basin, the Fennoscandian Border Zone (Poulsen and Riding, 2003, with earlier papers cited therein) up to the Peri-Baltic Syncline (Barski *et al.*, 2005). The Oxfordian/Kimmeridgian boundary is placed at the boundary of the dinoflagellate cyst zones DSJ 26 and DSJ 27 or between the subzones c and d of the *Scriniodium crystallinum* Zone. The foraminifers and radiolarians which occur in these beds can also be used in stratigraphical correlations (Wierzbowski A. *et al.*, 2015 a, with earlier papers cited therein).

The deposits at the Oxfordian/Kimmeridgian boundary of the Peri-Baltic Syncline of north-eastern Poland show marked differences in thickness and facies development ranging from normal pelagic sediments with radiolarian faunas up to strongly condensed deposits associated with stratigraphical hiatus. The origin of these strongly contrasting deposits was possibly related to tectonic movements during the earliest Kimmeridgian (Wierzbowski A. *et al.*, 2015 a). The stratigraphical unconformity recognized is very close in age to the base of the sequence stratigraphic unit interpreted over wider areas of northern Europe, which at least partly seems to be tectonically controlled. Such an unconformity, except in the area of southern England discussed above, is observed in the Danish Basin and the Fennoscandian Border Zone of southern Scandinavia (Nielsen, 2003) and it may occur also on the Russian Platform on its northern edge, close to the Baltic Shield, in the Timan-Pechora Basin and the Mesen Syncline (Vishnevskaya *et al.*, 1999).

Russian Platform: Detailed biostratigraphical studies on the Oxfordian/Kimmeridgian boundary were originally presented by Mesezhnikov *et al.* (1989) from the Makariev section at Unzha river in the central part of the Moscow Syncline. This study resulted in recognition of the ammonite succession of the Boreal Oxfordian up to the lowermost Kimmeridgian (Mesezhnikov, Kalacheva and Rotkyte *in*: Mesezhnikov *et al.*, 1989) as well as of the relevant foraminiferal zonal scheme (Azbel *in*: Mesezhnikov *et al.*, 1989) for the Russian Platform. The successive studies of the neighbouring section at Mikhailenino resulted in the elaboration of the Subboreal and Boreal ammonite succession at the Oxfordian/Kimmeridgian boundary (Główniak *et al.*, 2010) which became the basis for the detailed interpretation of the stratigraphical ranges of the foraminiferal zones (Ustinova, 2012).

The ammonites occurring at the Oxfordian/Kimmeridgian boundary in the Mikhailenino section are represented by both Subboreal Aulacostephanidae and Boreal

Cardioceratidae. The characteristic NW European Subboreal assemblage of *Ringsteadia* and *Microbiplices* is typical of the uppermost Oxfordian Pseudocordata Zone. The overlying Subboreal assemblage composed of representatives of *Vineta*, *Pictonia* (the latter are different from the NW European representatives of the genus – somewhat similar to the recently established genus *Vielunia* – but being more evolute), and *Prorasenia* - is typical of the lowermost Kimmeridgian of north-eastern Europe. The boundary between the Oxfordian and Kimmeridgian is very well marked by the appearance of the Boreal Cardioceratidae – *Amoeboceras* (*Plasmatites*) represented by typical species of the subgenus like *P. praebauhini*, *P. bauhini*, *P. lineatum* – which makes possible very close correlation with the Flodigarry section at Staffin Bay in Skye (Główniak *et al.*, 2010). Similar data on the stratigraphical distribution of the Subboreal and Boreal ammonites in the sections around Moscow have been recently presented by Rogov (2015 a) who shows that the Oxfordian/Kimmeridgian boundary corresponding closely to that of the standard section on Skye may also be recognized here. **A special attention should be paid to the occurrence in the basal part of the Kimmeridgian on the Russian Platform of a new representative of the subgenus *Plasmatites* which is characterized by a strong development of the primary ribs to a very weak development of the secondary ribs (Rogov, 2015 a). This form corresponds well to “*Cardioceras*” *zietenii* (Rouiller) as illustrated by Nikitin (1916, pl.1: 10-13) which seems also close to *Amoeboceras gerassimovi* Mesezhnikov, Kalacheva et Rotkyte as described by Mesezhnikov *et al.* (1989, p. 85-86, pl. 26: 3-7) although the latter shows a more dense ribbing (Fig. 6: 7-8ab).**

The foraminiferal assemblages typical of the Russian Platform make possible the recognition of two foraminiferal zones in the uppermost Oxfordian and the lowermost Kimmeridgian: the *Lenticulina russiensis* - *Epistomina uhligi* Zone and the *Lenticulina kuznetsovae* - *Epistomina praetatarsiensis* Zone (see Azbel and earlier papers cited *in*: Mesezhnikov *et al.*, 1989). The boundary between these zones runs somewhat above the basal part of the Kimmeridgian – in the lowermost part of the Bauhini Zone (Ustinova, 2012).

Northern Central Siberia: The northern Siberian sections (Nordvik peninsula, Chernokhrebetnaya river and Levaya Boyarka river sections) were recently discussed by Wierzbowski A. and Rogov (2013) and Nikitenko *et al.* (2015; see also earlier papers cited therein), where also the position of the Oxfordian/Kimmeridgian boundary has been considered. According to Rogov and Wierzbowski A. (2009, pl. 2: 3-4) the base of the Oxfordian/Kimmeridgian boundary in the Nordvik section is defined by the occurrence of

representatives of the subgenus *Plasmatites* indicative of the Bauhini Zone. On the other hand, Nikitenko *et al.* (2015, pl. 1: 15-17) illustrated specimens attributed to *Amoeboceras rosenkrantzi* Spath and *Amoeboceras (Amoebites) bayi* Birkelund et Callomon found nearly at the same level in the section. They argued that their co-occurrence (the former indicative of the Rosenkrantzi Zone of the uppermost Oxfordian, the latter indicative of the basal part of the Kitchini Zone of the lowermost Kimmeridgian) excludes the occurrence of the Bauhini Zone from the section. The specimens attributed to *A. bayi* by Nikitenko *et al.* (2015, pl. 1:16-17) are poorly characteristic of the species, however, being generally smaller and showing different ornamentation – without the smooth spiral band on the upper part of the whorl-side, and the presence of short but accentuated secondary ribs (*cf.* Birkelund and Callomon, 1985, p.13-16, pl. 1: 12). It is suggested, that the specimens attributed to *A. bayi* by Nikitenko *et al.* (2015) cannot be placed in that species; some of the features observable – like the small size and the type of ornamentation, may even suggest their possible relation with weakly ornamented representatives of the subgenus *Plasmatites*.

Other sections of northern Central Siberia did not yield precise information on the position of the Oxfordian/Kimmeridgian boundary: this occurs possibly within an interval represented by cross-bedded sandstones generally barren but the lowermost part of which yielded *Amoeboceras ex gr. rosenkrantzi* indicative of the uppermost Oxfordian Rosenkrantzi Zone in the Chernokhrebetnaya section (Aleynikov and Meledina, 1993). The Levaya Boyarka section yielded in its lower part an assemblage of ammonites indicative of the uppermost Oxfordian, including *A. schulginae* Mesezhnikov, known also from the lower part of the Bauhini Zone of the lowermost Kimmeridgian (Mesezhnikov, 1984, and earlier papers cited therein; see also Wierzbowski A. and Rogov, 2013). **Recent studies of the Levaya Boyarka and Kheta sections showed, moreover, the presence of the subgenus *Plasmatites*, co-occurring with *A. aff. schulginae*, both indicative of the Bauhini Zone of the lowermost Kimmeridgian (Rogov, 2015 b, and unpublished data based on new collections 2015; see Fig. 6: 9).** These data given strongly suggest the possibility of recognition of the Oxfordian/Kimmeridgian boundary in northern Central Siberia as defined in the standard Flodigarry section.

A different opinion on the stratigraphical importance of the Bauhini Zone was given by Nikitenko *et al.* (2013). The authors directly question the possibility of recognition of this zone in the Siberian sections, and consider, moreover, that there are “no sufficient data for the definition” of this zone because of the uncertain status of the subgenus *Plasmatites*, with the

problematic species composition of the subgenus, and unclear difference between some *Plasmatites* and early representatives of the subgenus *Amoebites* – especially *A. bayi*. However, the subgenus *Plasmatites* does represent a well defined and closely related assemblage of species as previously indicated by Matyja and Wierzbowski A. (1988). The ammonites of the subgenus occur in a fairly narrow, well defined interval in the *Amoeboceras* succession characterized by the incoming of “small-sized microconchs” (when compared with the under and overlying deposits), and are markedly different in many features, including the character of the ventral side of the whorl, from the subgenus *Amoebites* (see Wierzbowski A. and Rogov, 2013, and earlier papers cited therein). Alfirov *et al.* (2015) expressed a similar opinion distinguishing the Bauhini Zone as the basal zone of the Kimmeridgian in Western Siberia.

Franz-Josef Land: The Wilczek Land is known for a long time as an area where the Oxfordian-Kimmeridgian transitional deposits are exposed (Mesezhnikov and Shulgina, 1982). Among the ammonites described from these deposits, the most stratigraphically important has been “*Amoeboceras cf. ravni*” of Meledina *et al.*, 1979 (pl. 2: 7). This form is very close to ammonites referred to as *A. aff. schulginae* by Matyja *et al.* (2006, fig. 6: k-n) from the Flodigarry section at Staffin Bay, and it clearly indicates the presence of the Bauhini Zone. New important ammonite findings were made in the year 2015 by Nikolay Zverkov (Moscow), who discovered an assemblage composed of *Amoeboceras rosenkrantzi* and *Plasmatites*, both found in a single concretion (Fig. 6: 10-12). This assemblage is indicative of the lowermost part of the Bauhini Zone which correlates strictly with the *P. flodigarriensis* horizon of the basal part of the Baylei Zone.

Barents Sea and Norwegian Sea: The cores drilled in the southwestern Barents Sea and in the northeastern Norwegian Sea revealed the presence of an ammonite succession near the boundary of the Oxfordian and Kimmeridgian (Wierzbowski A. and Smelror, 1993; Wierzbowski A. *et al.*, 2002). The ammonites are mostly Boreal representatives of the genus *Amoeboceras*, especially fully recognized in the cores from the Barents Sea, and with some admixture of Subboreal Aulacostephanidae in the cores from the Norwegian Sea. The Boreal *Amoeboceras* are represented by *A. rosenkrantzi* Spath which is normally typical of the Rosenkrantzi Zone of the uppermost Oxfordian, and representatives of the subgenus *Plasmatites* typical of the Bauhini Zone of the lowermost Kimmeridgian. The latter are known in two ammonite assemblages which follow each other: a lower one composed of *A.(P.) praebauhini* (Salfeld) together with *A. rosenkrantzi* which carries on from the

underlying uppermost Oxfordian deposits, and a higher one composed of *A.(P.) bauhini* (Oppel) and a form similar to *A. schulginae* Mesezhnikov. This succession corresponds precisely to that of the Boreal *Amoeboceras* as recognized in the standard Flodigarry section at Staffin Bay (Matyja *et al.*, 2006, p. 397).

Oxfordian/Kimmeridgian boundary in the Submediterranean-Mediterranean successions as a consequence of correlation with the Subboreal-Boreal successions

General information on the ammonite subdivision: The stratigraphical interval considered ranges from the uppermost Bifurcatus Zone (the Grossouvrei Subzone), through the Hypselum Zone up to the Bimammatum Zone of the Submediterranean/Mediterranean zonal scheme. The treatment of the Hypselum Zone as an independent zone instead of a subzone comprising the lower part of an extended Bimammatum Zone results from the well-defined character of its fauna (*e.g.* Meléndez *et al.*, 2006), as well as of the correlation purposes related to the recognition of the consistent Oxfordian/Kimmeridgian boundary (*e.g.* Wierzbowski A., Matyja, 2014 a). The biochronostratigraphical subdivision of the Hypselum Zone is based on ammonites mostly of the genus *Epipeltocheras* by Bonnot *et al.* (2009; see also earlier papers cited therein) in the Poitou area, western France. These authors distinguished three units of the status of ammonite-horizons which have been subsequently treated as independent ammonite subzones (Wierzbowski A., Matyja, 2014a,b): the Semimammatum Subzone, the Semiarmatum Subzone and the Berrense Subzone. The analysis of the ammonite distribution given below is based also on data from the Polish Jura sections – especially its northern part – the Wieluń Upland (sections at Katarowa Góra and Bobrowniki) which have been published recently (Wierzbowski A., Matyja, 2014 b with earlier papers cited therein; see also Fig. 5 herein). In addition, we use data from sections in the Franconian Alb and the Swabian Alb (*e.g.* Schweigert, Callomon, 1997; Jantschke, 2014 with earlier papers cited therein).

The Semimammatum Subzone shows the presence of a characteristic assemblage of aspidoceratids. Besides *Epipeltocheras semimammatum*, there occur also *Euaspidoceras*, with species like *E. hypselum* (Oppel) which is especially common in this subzone although it ranges higher into the Semiarmatum Subzone. **It should be remembered, however, that the roots of the macroconch genus *Clambites* are in the genus *Euaspidoceras*. Thus, some late representatives of *Euaspidoceras* may be treated as the “hidden” macroconch counterparts of**

the earliest *Epipeltoceras* microconchs (Bonnot *et al.*, 2009; see also Schweigert, 1995) – and in consequence compared with the genus *Clambites*. Such interpretation was given for *Euaspidoceras hypselum* (Oppel) by Schweigert and Callomon (1997) and for *E. striatocostatum* (Dorn) by Wierzbowski A. and Matyja (2014 b). The top of the Semimammatum Subzone is also marked by the incoming of a new *Neaspidoceras* fauna such as *N. radisense* (d’Orbigny) which occurs commonly in the Semiarmatum and Berrense subzones (Bonnot *et al.*, 2009; Wierzbowski A., Matyja, 2014 b). The Semimammatum Subzone shows also the development of a special assemblage of Mediterranean passendorferiids – grouped around *Graefenbergites idoceroides* (Dorn) (see Schairer, Schlampp, 2003; Wierzbowski A., Matyja, 2014 b, and earlier papers cited therein). The Semiarmatum Subzone shows the presence of the first representatives of the genus *Praeataxioceras* which become common [and are represented by *P. virgulatus* (Quenst.)] in the overlying Berrense Subzone (Bonnot *et al.*, 2009; Wierzbowski A., Matyja, 2014 b). The topmost part of the Hypselum Zone – the Berrense Subzone - is characterized moreover by the incoming of several new groups of ammonites which are recorded also from the lower part of the Bimammatum Zone. These include some aspidoceratids such as the genus *Clambites*, but also some oppeliids – like *Taramelliceras (T.) costatum* (Quenstedt), *Glochiceras (Lingulaticeras) bobrownikiense* Wierzbowski et Głowniak, and *T. (Richeiceras) jaeggii* Quereilhac (Zeiss, 1966; Bonnot *et al.*, 2009; Wierzbowski A., Matyja, 2014 b, and earlier papers cited therein).

The Bimammatum Zone is subdivided herein into the Bimammatum Subzone and the Hauffianum Subzone (*e.g.* Wierzbowski *et al.*, 2010), units which are also recognized in all other interpretations of the Bimammatum Zone. The base of the Bimammatum Zone (and the base of the Bimammatum Subzone) is marked by appearance of the very characteristic species *Epipeltoceras bimammatum* (Quenstedt). It is also marked by the occurrence of new groups of aspidoceratids of the genera *Aspidoceras*, *Physodoceras*, *Pseudowaagenia* and *Amoebopeltoceras*, to the almost total disappearance of the older *Euaspidoceras* species, besides *E. costatum* (Dorn), and the related heavily ornamented *Epaspidoceras* (see *e.g.* Schweigert, 1995; Schweigert, Callomon, 1997; Oloriz *et al.*, 1999; Bonnot *et al.*, 2009; Wierzbowski A., Matyja, 2014 b; Jantschke, 2014; Schweigert, Jantschke, 2015, and earlier papers cited therein). A new group of oppeliids of the *Metahaploceras* group - appears in a lower part of the Bimammatum Subzone, but somewhat above its basal part (Wierzbowski A. *et al.*, 2010).

Special attention should be paid to the stratigraphical distribution of the oppeliid species *Ochetoceras marantianum* (d'Orbigny). Its occurrence has been treated as indicative of the Marantianum Zone of de Grossouvre (1896, fide Enay *et al.*, 1971) which has been correlated with the Bimammatum Subzone. It should be remembered, however, that the species in question, although commonly occurring in the base of the Bimammatum Subzone, seems to appear somewhat below - in the upper part of the Hypselum Zone, mostly in the Berrense Subzone (see *e.g.* Schuler, 1965; Zeiss, 1966; Meléndez, 1989; also data given below).

The Bobrowniki section in the Wieluń Upland in central Poland yielded recently specimens closely related to *O. marantianum* from the upper part of bed D, and from bed C which modify somewhat the stratigraphical interpretation of the succession as described by Wierzbowski A and Matyja (2014 b, fig. 2). The most complete of the specimens collected is a large, fully grown form which shows rather loosely-spaced concave ribs in the ventrolateral part of whorl typical of the species, some of which bifurcate very near the well-developed lateral groove (Fig. 6: 1a,b). It should be remembered that this last feature differentiates the specimen studied (similarly as other fragmentary preserved specimens from beds D and C) from the bulk of representatives of the species in question from the lowermost part of the Bimammatum Subzone (*e.g.* Bonnot *et al.*, 2009, pl. 5: 14-15, 17-18) where the ribs split well above the ventral groove, usually in a markedly higher position. According to that feature, as well as to the fact that the specimens from the Bobrowniki sections are the oldest reported so far representatives of the species in the succession of the Wieluń Upland studied, it may be suggested that they are indicative of the upper part of the Hypselum Zone – the Berrense Subzone (Fig. 5). This changes somewhat the stratigraphical interpretation of the deposits which yielded the ammonites in question, previously referred to by Wierzbowski A. and Matyja (2014 b, fig.2) as representing a non strictly-defined interval from the uppermost part of the Hypselum Zone to a lowermost part of the Bimammatum Zone. This interpretation also makes closer correlation possible between the particular zonal schemes at the Oxfordian/Kimmeridgian boundary, and will be discussed below.

Correlation between the Submediterranean/Mediterranean succession and the Suboreal and Boreal successions: The correlation is possible on the basis of the detailed analysis of the sections in which ammonite faunas indicative of the particular successions occur together. Such sections are known in the Polish Jura in central Poland, and some other

areas of Poland, but also in other areas of the Submediterranean Europe such as the Franconian Alb and the Swabian Alb in southern Germany, and northern Switzerland.

The uppermost Oxfordian Subboreal Pseudocordata Zone is subdivided into four subzones: the Caledonica Subzone, the Pseudoyo Subzone, the Pseudocordata Subzone and the Evoluta Subzone (Wright, 2003, 2010, and earlier papers cited therein). The lowest of these subzones has been recognized in the Staffin Bay section (Sykes, Callomon, 1979; Matyja *et al.*, 2006), and for a long time not found in any section elsewhere. The species *Ringsteadia caledonica* (Sykes et Callomon) represented both by micro and macroconchs, **showing similar type of ornamentation but differing in size and the character of aperture** has been discovered recently, however, in the cores in the Peri-Baltic Syncline in northern Poland. It co-occurs here, similarly as in the Skye section, with Boreal *Amoeboceras* indicative of the upper part of the Boreal Regulare Zone, and both these faunas are placed in between the occurrences of the Submediterranean ammonites indicative of the upper part of the Submediterranean Bifurcatus Zone, and a lower part of the Hypselum Zone, respectively (Wierzbowski A. *et al.*, 2015 a). Correlations based on the analysis of the oldest Subboreal *Ringsteadia* forms in the Submediterranean succession of central Poland and southern Germany (Wierzbowski A., Matyja, 2014 b) gave the same results. Therefore it may be inferred that the base of the Subboreal Pseudocordata Zone (*i.e.* the base of the Caledonica Subzone) runs in an upper part of the Submediterranean Bifurcatus Zone, whereas the top of the Caledonica Subzone should be placed not very far from the Bifurcatus/Hypselum zonal boundary (Fig. 7). Independently the top of the Boreal Regulare Zone, corresponding to the base of the Boreal Rosenkrantzi Zone, runs nearby, but slightly below the top of the Submediterranean Bifurcatus Zone (Wierzbowski A., Matyja, 2014 b, and earlier papers cited therein).

The Subboreal Pseudoyo Subzone corresponds to the bulk of the Semimammatum Subzone representing the lower part of the Submediterranean Hypselum Subzone, and the same interval corresponds to the lower part of the Boreal Rosenkrantzi Zone – mostly its lower part - the Marstonense Subzone. This interpretation results from the occurrence in the Semimammatum Subzone of specimens very close to the Subboreal *Ringsteadia pseudoyo* Salfeld together with its microconchs – the early representatives of *Microbiplices* of the *M. procedens* (Oppenheimer) group, as well as of Boreal representatives of *A. rosenkrantzi* Spath (and the closely related small-sized *A. ovale* which may be treated as representing a wide spectrum of dwarfed-like and dwarfed forms of the *A. marstonense* – *A. rosenkrantzi*

group) (see Wierzbowski A., Matyja, 2014 a, b, with earlier papers cited therein; see also Matyja, Wierzbowski A., 2000).

The younger assemblage of Subboreal forms found in the Submediterranean succession includes additionally *M. microbiplex* (Quenstedt) which represents a younger *Ringsteadia* microconch, as well as *R. salfeldi* (Dorn) which has the appearance of a more boldly ribbed variant of the Subboreal *R. brandesi* Salfeld, as well as *R. teisseyreii* (Siemiradzki) which is very close to the Subboreal *R. pseudocordata* (Blake et Hudleston) [Wierzbowski A., Matyja (2014, b); see also Głowniak, Wierzbowski A.(2007), and Wright (2010)]. This assemblage of ammonites indicates the presence of the Subboreal Pseudoyo Subzone and/or the Pseudocordata Subzone (Wright, 2010). Because the ammonites in question were found in a part of the Submediterranean succession which may be correlated with an upper part of the Semimammatum Subzone and the Semiarmatum Subzone of the Hypselum Subzone - the Submediterranean interval indicated cannot be younger than some middle parts of the Subboreal Pseudocordata Zone – the Pseudocordata Subzone. The same stratigraphical interval yielded *A. rosenkrantzi* Spath indicative of the Boreal Rosenkrantzi Zone.

The youngest ammonite assemblage of the Subboreal Oxfordian recognized in the Polish Jura, in the stratigraphical interval corresponding to the Submediterranean Berrense Subzone, consists mostly of strongly ornamented representatives of *Microbiplices* which show a marked similarity to the Subboreal species *Microbiplices anglicus* Arkell. They differ only in less evolute coiling and hence are distinguished as the new subspecies *M. anglicus vieluniensis* Wierzbowski et Matyja (see Wierzbowski A, Matyja, 2014 b). There occur some specimens in the upper part of the stratigraphical range of this form, however, which show in the inner whorls thicker and somewhat more swollen primary ribs showing a lower point of division of the ribs. These specimens are interpreted as transitional between *Microbiplices* and *Prorasenia* (Fig. 6: 5). Whereas the occurrence of the species *Microbiplices anglicus* indicates the Pseudocordata Subzone, the occurrence of forms transitional between *Microbiplices* and *Prorasenia* is typical of the Evoluta Subzone of the Pseudocordata Zone of the uppermost Subboreal Oxfordian (see Matyja *et al.*, 2006; Wright, 2010). These data indicate that at least a bulk of the Submediterranean Berrense Subzone of the Hypselum Zone may be correlated with some middle and upper parts of the Subboreal Pseudocordata Zone (Fig. 7). The same stratigraphical interval in the Polish Jura sections yielded a few Boreal ammonites such as *Amoeboceras rosenkrantzi* and *A. subcordatum* (d'Orbigny) sensu

Salfeld (1916) the latter being closely related to *A. tuberculatoalternans* (Nikitin). The co-occurrence of these forms with the virtual absence of representatives of the subgenus *Plasmatites* is indicative of the upper part of the Boreal Rosenkrantzi Zone (Matyja *et al.*, 2006; Głowniak *et al.*, 2010; Wierzbowski A., Matyja, 2014b).

The topmost part of the deposits attributed to the Subboreal/Boreal uppermost Oxfordian of the Pseudocordata Zone and the Rosenkrantzi Zone in the northern part of the Polish Jura, in the Wieluń Upland (Bobrowniki section) shows the presence of an omission surface well-characterized by geochemical studies (Grabowski *et al.*, 2015; Wierzbowski A. *et al.*, 2015b; see also chapter on environmental and climatic conditions, herein). This omission surface delimits the occurrence of the uppermost Oxfordian Subboreal/Boreal faunal assemblages below from the occurrence of the lowermost Kimmeridgian ones above, and may be correlated with the tectonically enhanced omission surface (interpreted also in terms of sequence stratigraphy) commonly recognized in the Subboreal Province (see Wierzbowski A. *et al.*, 2015a).

Directly at and closely above the discussed omission surface, ammonites of the genus *Vineta* appear in the studied section at Bobrowniki in the Wieluń Upland in central Poland (Fig. 5). The assemblage consists both of fragments of macroconchs, as well as small microconchs (Fig. 6: 2-4). These show a marked similarity to previously illustrated specimens of *Vineta* obtained from younger deposits of the Bobrowniki section attributed to the Bimammatum Zone (Wierzbowski A. *et al.*, 2010, pl. 6: 6-7; pl. 7: 1-3). It should be remembered that the microconchs of *Vineta* closely resemble the much earlier *Microbiplices procedens* which is a microconch of early representative of the genus *Ringsteadia* - *R. pseudoyo*. The species *R. pseudoyo* is commonly encountered in a lower part of the Pseudocordata Zone, but a similar, although somewhat more evolute variant continues its occurrence up to the top of the zone in question (Wright, 2010), and such forms possibly gave rise to the genus *Vineta*. The occurrence of the genus *Vineta* in the north-eastern and central Europe was coeval with the appearance of the genus *Pictonia* in north-western Europe (Wierzbowski A., 2010 a; Wierzbowski A. *et al.*, 2015 a). Thus, the base of the Baylei Zone of the Subboreal lowermost Kimmeridgian as defined by the appearance of the genus *Pictonia* corresponds to the base of the Jaekeli Zone as defined by the appearance of the genus *Vineta*.

Another group of Subboreal ammonites is *Prorasenia* which appears directly at the base of the Baylei Zone in north-western European areas, including the standard Flodigarry

section at Staffin Bay, where it is treated as the microconch of the genus *Pictonia* (Matyja *et al.*, 2006). It should be remembered that the oldest representatives of *Prorاسenia* are found somewhat higher than the genus *Vineta*, about 1 metre above the omission surface in the studied section at Bobrowniki in the Wieluń Upland of central Poland (Wierzbowski A., Matyja, 2014 b). This *Prorاسenia* is interpreted as the microconch counterpart of the newly established macroconch genus *Vielunia* typical of the Subboreal areas of the north-eastern and central Europe which may be treated as the “involute analogues of true *Pictonia*” (Wierzbowski A., 1994; see also Wierzbowski A. *et al.*, 2010). It should be remembered that the ammonites of the genus *Vielunia* (as well as of the genus *Vineta*) were commonly included in the past to the genus *Ringsteadia* (see *e.g.* Matyja, Wierzbowski A., 1998, and earlier papers cited therein).

Ammonites of the genera *Vineta* and *Vielunia-Prorاسenia* are commonly encountered in the Bimammatum Zone (as well as the overlying Planula Zone) in the so-called German-Polish Subprovince of the Submediterranean Province stretching from central Poland, through the Bohemian Massif (where the remnants of original cover of the Jurassic deposits with aulacostephanids and cardioceratids are preserved, see Hrbek, 2014; see also Fig. 1 herein), and southern Germany down to the northern Switzerland (Matyja, Wierzbowski A., 1995). In the studied interval of the Bimammatum Subzone a number of forms have been reported which were attributed in many papers to the genus *Ringsteadia*, but which should be transferred nowadays either to the genus *Vineta* or to the genus *Vielunia*.

To the genus *Vineta* belong *int. al.*: in Poland - specimens originally described as “*Ringsteadia*” *submediterranea* by Wierzbowski A. (1978, pl. 3:1-3), later transferred to the genus *Vineta* by Wierzbowski A. *et al.* (2010) with its characteristic rapid increase in whorl height; in southern Germany - specimens of “*Ringsteadia flexuoides* (Quenstedt)” of Jantschke (2014, pl. 3: 7; pl. 4: 1) which seem very close to *Vineta submediterranea* (Wierzbowski). The giant specimens comparable with those of *Vineta jaekeli* of Dohm (1925, pl. 4: 1. 4-5) – the type species of the genus *Vineta*, include specimens from northern Switzerland - like some large specimens of “*Ringsteadia*” *magna* Gygi of Gygi (2003, figs 31-33) which are also similar to a large specimen of “*Ammonites vicarius*” of Moesch (1867, pl. 2: 1ab). All these specimens show generally weak (but poorly recognized) ornamentation of the inner whorls, and completely smooth outer whorls, but differ possibly in a less involute coiling of the inner whorls (*cf.* Wierzbowski *et al.*, 2010).

To the genera *Vielunia* (M)-*Prorrasenia* (m) belong *int.al.*: in Poland – *Vielunia dzalosisinensis* Wierzbowski et Głowniak and *Prorrasenia crenata* (Quenstedt) representing the dimorphic counterparts and illustrated by Wierzbowski A. *et al.* (2010, pl. 8: 2; pl. 9: 1-4; pl. 10: 1-5; see also older papers cited therein where the representatives of the genus *Vielunia* were compared with the genus *Ringsteadia*); in southern Germany - to this group belong possibly specimens of *Prorrasenia* described by Jantschke (2014, pl. 3: 5-6); in northern Switzerland – a large specimen described to as “*Ringsteadia*” *limosa* (Quenstedt) by Gygi (2003, fig. 25) as well as “*Ringsteadia*” *flexuoides* (Quenstedt) of Gygi (2003, fig. 30) which both seem very close to *V. dzalosisinensis*.

A special attention should be paid to the species “*Ringsteadia*” *flexuoides* (Quenstedt) which is based on specimens described and illustrated by Quenstedt (1888, pl. 107: 6, 15; see also Ziegler, 1973) from the **Bimammatum Zone** (G.Schweigert, *pers. inf.*, see also Schweigert and Callomon, 1997), and not from the Planula Zone as often given in the past which resulted from a wrong interpretation of the “*Bimammatum*” Member as the “*Weißjura beta*”. The specimens most close to those of that species originally described by Quenstedt are those described by Wierzbowski A. (1970, pl. 1: 1-3, pl. 2: 1-2) from the Planula Zone of central Poland. The representatives of this species occur also in older beds, such as a large specimen referred to as “*Ringsteadia*” *cf. submediterranea* by Gygi (2003, fig. 27) possibly from the Bimammatum Zone, which shows both the character of coiling and well as the rib density similar to those of “*R.*” *flexuoides*. The true “*Ringsteadia*” *flexuoides* possibly represents a strongly involute species of the genus *Vielunia* as shown by markedly developed secondary ribs with a lower point of rib furcation (Wierzbowski A. *et al.*, 2015 a). The species shows dischizotomous separation of the secondaries – which arise often in triplicate sheaves, and forward-swept ribbing. A similar type of ribbing is shown in *Ringsteadia frequens* Salfeld as revised by Wright (2010) from the topmost part of the Pseudocordata Zone which is, however more evolute, especially on the inner whorls. Some similarity may be also observed between *Ringsteadia evoluta* Salfeld from the uppermost Pseudocordata Zone and strongly ornamented representatives of *Vielunia* such as *V. dzalosisinensis* and its descendant *V. limosa* (*cf. e.g.* Wierzbowski A., 1970; Wright, 2010). It may be concluded thus that the ammonites of the genus *Vielunia* preserved some features of the latest representatives of the true British *Ringsteadia* which resulted in the past in treatment of all these forms as representing a single group of species.

There is possible, however a different interpretation of the systematic position of the species "*Ringsteadia*" *flexuoides* (Quenstedt). Because this form shows many features in common with older representatives of the genus *Ringsteadia*, it may represent the continuation of the main *Ringsteadia* lineage, and in fact may belong to the genus *Ringsteadia*. Such interpretation assumes the occurrence of the genus *Ringsteadia* in the earliest Kimmeridgian in the Submediterranean province after its total extinction at the end of the Oxfordian in the Subboreal province. According to this interpretation the genera *Vielunia*, *Vineta* and *Ringsteadia* developed in parallel lineages representing the co-occurring, possibly sympatrically developed genus-rank taxa.

The Bimammatum Subzone in the so-called German-Polish Subprovince of the Submediterranean Province mentioned above yielded also Boreal ammonites. These include mostly representatives of the subgenus *Plasmatites* such as *Amoeboceras* (*P.*) *praebauhini* Salfeld and *A. (P.) lineatum* (Quenstedt) described and illustrated from the northern part of the Polish Jura of central Poland (Wierzbowski A. *et al.*, 2010, pl. 6: 1-2) as well from southern Germany (Schweigert, 2000, pl. 1: 8; Jantschke, 2014, pl. 1: 3). The occurrence of these ammonites is indicative of the Bauhini Zone of the lowermost Boreal Kimmeridgian. It is worth noting that some ammonites referred to or being close to the Boreal species *Amoeboceras rosenkrantzi* Spath were discovered also in well dated deposits of the Submediterranean Bimammatum Subzone in southern Germany [Schweigert (2000, fig. 2ab, pl. 1: 7), Jantschke (2014, pl.1: 4-5)]; and that the deposits of the Bimammatum Subzone yielded specimens closely related to *Amoeboceras tuberculatoalternans* (Nikitin) in northern Switzerland [Atrops *et al.* (1993, pl. 1: 14); Gygi (2000, pl.10: 3); cf. also Gygi (1969, fig. 2)]. The occurrence of both these species together with *Plasmatites* indicates the lowermost part of the Boreal Bauhini Zone (*cf.* Matyja *et al.*, 2006). The reasoning is as follows: as well as distinguishing the Rosenkrantzi Zone at Flodigarry, *A. rosenkrantzi* and *A. schulginae* (close to *A. tuberculatoalternans*) occur still in the basal Kimmeridgian (*flodigarriensis* horizon), so their presence along with *Plasmatites* indicates the correlation of the Bimammatum Subzone with the lower part of the Baylei Zone.

The results of the foregoing is that the boundary of the Oxfordian and Kimmeridgian as defined on the basis of the Subboreal (the boundary between the Pseudocordata and the Baylei/Jaekeli Zone) and the Boreal succession (the boundary between the Rosenkrantzi Zone and the Bauhini Zone) runs very close to the boundary between the Hypselum Zone and the Bimammatum Zone in the Submediterranean succession (Fig. 7).

Position of the Oxfordian/Kimmeridgian boundary in other Submediterranean – Mediterranean areas

The Oxfordian/Kimmeridgian boundary according to the correlation given above may be traced also in other Submediterranean and Mediterranean areas where the ammonites of the Subboreal/Boreal affiliations are practically unknown or become very rare. The examples discussed relate to the successions from “classic” southern European areas such as Southeastern France and southwestern Iberian Chain and the Prebetic zone of Spain in the west, as well as some areas of central Asia (northern Iran) in the east.

Southeastern France: The transitional beds between Oxfordian and Kimmeridgian are well represented in the whole Southeastern France basin (Subalpine chains), and in its Southern (Provençal margin) and Western margins (Ardèche margin). The area shows the well-exposed, thick and continuous natural sections which yield numerous ammonite faunas of the Hypselum and Bimammatum zones as well as of the underlying and overlying deposits (of the Bifurcatus Zone and the Hauffianum Subzone, respectively), collected from many years by F. Atrops (collections preserved in Lyon University). The litho- and biostratigraphic characteristics of the successions are given in some synthetic publications (Atrops, 1984, 1994; Atrops *et al.*, 1989), but there are only a few detailed studies on particular sections and ammonites, such as unpublished thesis of Duong (1974) and that of Lhamyani (1985) from the Provençal margin. Preceding the future publication showing the detailed description of the main sections and ammonites, some general data summarizing the general knowledge on the ammonite succession at the Oxfordian/Kimmeridgian boundary in Southeastern France are given below. Everywhere, the lower boundary of the Bimammatum Zone treated as the base of the Kimmeridgian in the Submediterranean-Mediterranean subdivisions, is well characterised by the first appearance of the index-species *Epipeltoceras bimammatum* (Quenstedt). The most fossiliferous sections are located in the Provence and Ardèche margins, whereas in the basin the best known reference section is that at Châteauneuf-d’Oze (Hautes-Alpes) in the Subalpine chains (Atrops, 1982, 1994).

In the Ardèche region, two different types of facies successions are recognized. The marginal “Ardèche” facies are the best represented showing a common stratigraphic gaps at the Upper Callovian - Lower Oxfordian (reference sections near Les Vans), and the presence of the “Grumeleux” facies from the Plicatilis Zone of the Middle Oxfordian up to the Bifurcatus Zone of the lowermost part of the Upper Oxfordian. In some areas, however, the

transition from the marginal to the basinal facies can be observed, and it becomes even quite rapid, when going to the east. The basinal succession is characterized (for example in Crussol and Le Chénier sections near La Voulte) by the appearance of the “Terres Noires” facies (Lower Oxfordian with pyritic ammonites), by the successive reduction of the importance of the “Grumeleux” levels, as well as by development of a thick succession of deposits from the Plicatilis Zone to the Bifurcatus Zone. From the Bimammatum Zone, however, these differences tend to obliterate. Facies and thicknesses in both types of successions become very similar what allows the precise lithological correlations between even distant sections.

The reference sections of the “Ardèche” facies zone are located near Les Vans (Ardèche). The Bifurcatus Zone (18 m in thickness) shows the dominantly marly development with rare “Grumeleux” calcareous banks (Chanabier Beds; Dromart, 1986), and it yields, the successive species of the genus *Dichotomoceras* characteristic of the particular parts of the zone found at different levels. Still younger deposits of the Hypselum Zone (24 m in thickness) are well characterized by the occurrence of *Epipeltoceras semimammatum* (Quenstedt), in a calcareous hard level (“Brown Banks”, 1.5 m thick) at the base of the zone. This lithological unit is a good reference level in the whole Southeastern France basin and its margins. The younger deposit interval consists of soft intercalated marls and marly limestones (“Joyeuse Beds”), generally with few ammonites. The “Grumeleux” intercalations practically disappear here. Still higher, however, a change in lithology is observed and the deposits become evidently more calcareous. These deposits form spectacular cliffs of the Upper Jurassic rocks well seen in the landscape (“Pouzin Limestones” Formation, Atrops and Elmi, 1984). The ammonites are much more numerous, allowing the recognition of the Bimammatum, Hauffianum and Planula zones in this thick and continuous calcareous succession. A subdivision into three units well characterized by their lithology and fauna can be easily made. The lower unit (a lower cliff, 8 metres in thickness) provides the first representatives of the true *E. bimammatum*, associated with the first but always rare, representatives of the *Aspidoceras* (*Aspidoceras*) *atavum* (Oppel) group. This unit is separated from the upper one (composed of much thicker and hard limestones - 65 metres in thickness) by a more soft calcareous unit (9-10 metres in thickness) representing the so-called “*Praeataxioceras* interval” (Atrops, 1984) - very rich in ammonites. The ammonites *Praeataxioceras* of the *virgulatus* group are here dominant; on the other hand they co-occur with *E. bimammatum* (Atrops, 1994, pl. 4: 9), and commonly occurring *Taramelliceras costatum* (Quenstedt). The species *E. bimammatum* disappears at the top of the

“*Praeataxioceras* interval”. It is worth noting that *E. bimammatum* occurs here continuously in a 10 metres thick interval, what allows a precise analysis of its morphological variation during the Bimammatum Zone (different successive chronological subspecies ?; studies in progress by F. Atrops).

Above the last occurrence of *Epipeltoceras bimammatum* and the first appearance of *Taramelliceras hauffianum* (Oppel), there exist a 10 metres - thick interval of limestones which yields mainly *Orthosphinctes*, *Taramelliceras* of the *costatum* group and different species of *Metahaploceras*. A similar interval without *E. bimammatum* and *T. hauffianum* is recognized in Germany, where it was referred to as (except its upper part) the *tizianiformis* horizon (Schweigert and Callomon, 1997). The name after “*Perisphinctes*” *tizianiformis* (Choffat) is not appropriate, however, to characterize this interval, because the type-specimen of the Choffat’s species comes from deposits dated to the Plicatilis Zone of Portugal, and thus it is much older than the interval in question (Meléndez *et al.*, 2006, with earlier papers cited therein). The proper systematic interpretation of the *Orthosphinctes* ammonites discussed needs additional study (actually in progress), and these are provisionally referred to as *Orthosphinctes* aff. *tiziani* (Oppel). The occurrence of *T. hauffianum*, in 3.5 metres thick deposits overlying the interval discussed characterizes the Hauffianum Zone. The total thickness of the deposits of the “Ardèche” facies corresponding to the Hypselum, Bimammatum and Planula zones attains 55 metres.

The “Terres Noires” facies succession is well recognized in the reference section at Crussol in Ardèche. The succession is thick, continuous and rich in ammonites in all levels from the Bifurcatus Zone up to the Tithonian Hybonotum Zone. The Bifurcatus Zone is represented by a well-exposed c. 50 m - thick monotonous marls with rare limestone beds, and locally encountered intercalations of the “Grumeleux” facies. The successive species of *Dichotomoceras* make possible recognition of the Stenocycloides Subzone and the Grossouvrei Subzones. The younger dominantly marly deposits, belong to the Hypselum Zone (54 m). These deposits begin with a thick (3.5 m) brown limestone beds, and the whole Hypselum Zone is much thicker here than in the “Ardèche” facies succession at Les Vans (54 m instead of 24 m). A lower part of the zone belongs to the Semimammatum Subzone - with *E. semimammatum* found up to 16 metres from the base. The Bimammatum Zone begins at the base of the massive cliff of the “Pouzin Limestone” Formation similarly as in the “Ardèche” facies area. The species *E. bimammatum* occurs at different levels in a more soft part of the succession which corresponds to the “*Praeataxioceras* interval” (11 metres in

thickness). This interval is characterized by common occurrence of *Praeataxioceras virgulatus* (Quenstedt) together with *Taramelliceras costatum* (Quenstedt), and *E. bimammatum* ranging up to the top of this interval. The first *T. hauffianum* appears about 18 metres higher than the highest *E. bimammatum*, and it co-occurs with common ammonites of the *Metahaploceras* group. The latter are rare in the interval of 18 m below and in the Bimammatum Zone. Of the ammonites of the genus *Ochetoceras* – the species *Ochetoceras marantianum* (d'Orbigny) occurs only in the Hauffianum Subzone, whereas the species *Ochetoceras semifalcatum* (Oppel) occurs only in the Bimammatum Subzone. The first representatives of *Subnebrodites*, close to the *S. planula* group, appear just above the last *T. hauffianum*. The Planula Zone (including the Galar Subzone) attains nearly the same thickness both in Crussol (51 m) and in Les Vans (53 m) sections. The Hypselum-Bimammatum-Hauffianum zone interval (89 m) is thicker in Crussol than in Les Vans (55 m).

In the Dauphinois basin itself (Subalpine Chains), the basinal deposits are well exposed in the Southern Subalpine chains (Diois, Baronnies, Dévoluy). The reference sections are Châteauneuf-d'Oze (Atrops, 1982, 1984, 1994) and Saint-Geniez (Atrops, 1982). The upper part of the “Terres Noires” Formation (Lower Oxfordian and lower part of the Middle Oxfordian) is well developed here. The Châteauneuf-d'Oze section (South of Dévoluy) is continuous from the Upper Oxfordian Hypselum Zone to the Acanthicum Zone of the Kimmeridgian. Its detailed stratigraphic study was given by Atrops (1982), and it was supplemented by micropaleontological, sedimentological and geochemical works, but its magnetostratigraphical study by J.Ogg gave no results. The lower part of the section, dominantly calcareous (70 m), is dated to the Hypselum, Bimammatum, Hauffianum and Planula zones (Atrops, 1982, 1994). The ammonites are here less numerous than in Ardèche (Les Vans and Crussol sections), but the “*Praeataxioceras* interval” (6,5 m in thickness) with many ammonites of the Bimammatum Zone is also well recognized here; these include: *E. bimammatum*, *E. treptense* (Atrops, 1994, pl. 4: 10), *T. costatum*, *Orthosphinctes* aff. *tiziani* (Atrops, 1994, pl. 2: 4) and abundant *Praeataxioceras* : *Praeataxioceras virgulatus* (Quenstedt) microconch (Atrops, 1982 pl. 19: 3) and *Praeataxioceras* ? *suevicum* (Siemiradzki) macroconch (Atrops, 1982, pl. 19: 1). Still above this assemblage - some rare ammonites are present : *T. hauffianum* and a primitive *Subnebrodites* of the *S. proteron* group (Atrops, 1994, pl. 1: 1) which characterize the Hauffianum Subzone and the Planula Zone.

The Saint-Geniez (Baronnies) section (Atrops, 1994) shows some particular features which makes it distinct from the successions normally recognized in the Subalpine basin from the Hypselum Zone up to the Upper Kimmeridgian. These are, most of all, the reduced thickness (only 25 m for the interval Bimammatum-Planula, instead of 70 m in the Châteauneuf-d'Oze section), and the presence of the “Grumeleux” facies. The Saint-Geniez area might be interpreted as representing a relatively shallow shoal area. The lower part of the section (7 m), has yielded in a 3 metres interval - a rich assemblage of ammonites characterizing the Bimammatum Zone : *Epipeltoceras bimammatum*, *E. treptense*, *Taramelliceras costatum*, *Orthosphinctes* aff. *tiziani* and *Praeataxioceras virgulatus*. Higher, the deposits become more hard and massive; they are ranging from the Hauffianum Subzone (9 m) to the Planula Zone (8 m). As in Les Vans and Crussol sections, the ammonites *Orthosphinctes tiziani* and *Taramelliceras* (*Metahaploceras*) are frequent, particularly in the Hauffianum Subzone.

In Provence, on the Southern margin of the Dauphinois basin (Haute-Provence Subalpine chains, Castellane arch), the transitional area between the platform deposits (Provençal Platform) and the basinal deposits (“Terres Noires” of the Lower Oxfordian and the base of the Middle Oxfordian) is well developed. It includes the most fossiliferous sections, from the Bifurcatus Zone to the Bimammatum Zone (Duong, 1974; Lhamyani, 1985; Atrops *et al.*, 1989). Higher in the sections, the ammonites become rare, and the Hauffianum Subzone and the Planula Zones are more difficult to recognize within a compact calcareous succession. As in “Ardèche” facies zone, the succession shows important stratigraphical gaps (Upper Callovian, Lower Oxfordian, base of the Middle Oxfordian) and is characterized by the presence of the “Grumeleux” facies. The thicknesses of deposits is much smaller than in Ardèche, for the interval from Transversarium to Bimammatum Zones attains only 11 metres in maximal thickness.

The whole area around Castellane is characterized by presence of sections which are very fossiliferous, and generally show the deposits of smaller thickness (Le Teillon, Chabrières, and others) (Duong, 1974 ; Lhamyani, 1985; Atrops, 1994). In the Teillon section, the Bifurcatus Zone having 5 metres in thickness is well characterized by numerous *Dichotomoceras*. Just above, *E. semimammatum* occurs in the reference hard “Brown Bank” (0, 65 m thick). The interval Hypselum-Bimammatum (6 m in thickness) shows the classical succession - from *E. semimammatum*, to *E. berrense*, and to *E. bimammatum*. In Chabrières section, the deposits are still thinner (2.80 m for the Bifurcatus Zone, 2.30 m for the

Hypselum Zone). The Hypselum Zone is characterized by numerous *Euaspidoceras* with *E. hypselum* at the top of the zone. The succession of the *Epipeltoceras* species is also very clear : *E. semimammatum* (Quenstedt), *E. semiarmatum* (Quenstedt), *E. berrense* (Favre). Just above, the transition to the Bimammatum Zone is indicated by the presence of *E. bimammatum* morphotype alpha (Bonnot *et al.*, 2009) which is followed, immediately at the base of the “Rauracian” cliff, by typical *E. bimammatum*, showing a more advanced morphology. This section is very important for studying in detail the boundary between the Hypselum and the Bimammatum zones.

In conclusion, in Southeastern France, there are many reference sections showing a full development of the Bimammatum Zone. The best are located in Ardèche (Les Vans and Crussol sections) showing a complete succession of the *Epipeltoceras* of the *bimammatum* group. The index-species is particularly important to recognize the base of the zone, and its vertical extension, and thus establishing of the boundary between the Oxfordian and Kimmeridgian. The Trept section (Enay, 1962, 1966), near Lyon, is also a good section for stratigraphical study: the Hypselum and Bimammatum zones attain here about 17 metres in thickness (5 metres of the Bimammatum Zone), and present a well recognized succession of *Epipeltoceras*. The ammonite faunas in Southeastern France are clearly of Submediterranean – Mediterranean character, whereas those of Subboreal/Boreal affinity are occurring very rarely (no reported Boreal *Amoeboceras* in the Bimammatum Zone, and very rare specimens in the Hypselum and Hauffianum-Planula zones).

New sections from the the southwestern Iberian Range and Pre-Betic Zone of Spain: The Oxfordian-Kimmeridgian Submediterranean-Mediterranean ammonite successions in the southwestern Iberian Range and the Pre-Betic Zone of Spain were the subject of several studies in the past (*e.g.* Meléndez, 1989; Olóriz and Rodríguez-Tovar, 1993; Olóriz *et al.*, 1999) and can be considered as representing the southern Submediterranean province. A study of the Fuenelspino de Moya sections in the westernmost part of the Castilla la Mancha province currently being undertaken is concentrated mostly on the succession of the Upper Oxfordian and basal Kimmeridgian as interpreted herein. The full description of the section and its ammonites will be published elsewhere, but some preliminary data on this succession by B.A.Matyja, F.Olóriz and A.Wierzbowski are presented herein. The section is important for general consideration because it shows a full succession of the Mediterranean-Submediterranean ammonites which may be compared with those described above from Submediterranean sections yielding also Boreal and Subboreal ammonites.

The Bifurcatus Zone is well characterized by the occurrence of the ammonites *Perisphinctes* (*Dichotomoceras*) spp. together with fairly common oppeliids – mostly of the genus *Ochetoceras* represented by *O. basseae* (Fradin), and *O. hispidiforme* (Fontannes); the base of the zone is marked by the common occurrence of *Larcheria*. The top of the zone is marked by the disappearance of *Dichotomoceras*, and the first ammonites appearing above are Passendorferiinae especially of the genus *Graefenbergites*, possibly belonging to *G. idoceratoides* (Dorn) which suggest already the base of the Hypselum Zone. This zone is characterized by the occurrence of oppeliids, mostly *Ochetoceras*, in common with the underlying Bifurcatus Zone deposits, but associated with very numerous aspidoceratids – including the genera *Euaspidoceras* (which appears already in the uppermost part of the Bifurcatus Zone together with *Mirosphinctes*), *Neaspidoceras*, and associated representatives of the genus *Epipeltoceras*. The latter makes possible the recognition of the Semimammatum Subzone (with *E. semimammatum*), the Semiarmatum Subzone (with *E. semiarmatum*) and the Berrense Subzone (with *E. berrense*). The top of the Berrense Subzone is marked by the appearance of forms transitional between *E. berrense* and *E. bimammatum*. The detailed ranges of some ammonite groups in the Hypselum Zone as recognized in the Fuentelspino de Moya sections are very similar to those described previously in other areas in Europe of the Submediterranean Province (see e.g. Bonnot *et al.*, 2009; Wierzbowski A., Matyja, 2014 b), and the results shown below are important for more general stratigraphical correlations: (1) the genus *Euaspidoceras* commonly occurs in a lower part of the Hypselum Zone; (2) the occurrence of the genus *Neaspidoceras* is recorded somewhat higher, at the top of the Semimammatum Subzone; (3) the oppeliids becomes very common in the upper part of the Hypselum Zone – in the Berrense Subzone – and are represented here both by small, weakly ornamented forms of the *Taramelliceras* (*Richeiceras*) group as well as more heavy ornamented *T. (Taramelliceras) costatum* (Quenstedt); (4) the first representatives of *Ochetoceras marantianum* (d'Orbigny) occur in the uppermost part of the Berrense Subzone.

It is worth noting that some of these observations can be used in the stratigraphical interpretation of the Oxfordian/Kimmeridgian boundary in the sections studied in the Submediterranean Province which do not yield the aspidoceratids important for stratigraphical subdivision of the Hypselum Zone. This is the case in the sections from the Wieluń Upland, central Poland, where the co-occurrence of the first representatives of *Taramelliceras costatum* (Quenstedt) and *Ochetoceras marantianum* (d'Orbigny) may be treated as indicative of the upper part of the Berrense Subzone (see Figs 5-6). Some of observations given shed

some light on the question of the stratigraphical interpretation of the Oxfordian/Kimmeridgian boundary in extra-European areas as discussed below.

Northern Iran: The Upper Jurassic ammonite successions of the Submediterranean-Mediterranean character occur mainly in northern Iran (Seyed-Emami, Schairer, 2010 and references therein): (1) Alborz Mountains (Dalichai and Lar formations), northern Iran; (2) Binalud Range (Dalichai Formation), northeastern Iran; and (3) Koppeh-Dagh (Chaman-Bid and Mozduran formations), northernmost East Iran (palaeogeographically related to the southern Russian Platform). The Oxfordian-Kimmeridgian successions are known also from the Tabas Block of Central Iran (Schairer *et al.*, 2003; Wilmsen *et al.*, 2009, and references therein). Ammonites have rarely been described from stratigraphically controlled bed-by-bed samplings, and the summary given below refers to more recent papers based on such successions.

In the northern East Alborz there is at least one section, in the region of Rostam-Kola, which has yielded a small, but controlled ammonite collection of the Hypselum-Bimammatum zones, described by Parent *et al.* (2012). The ammonite succession, from below, consists of the three following ammonite-assemblages: (1) *Passendorferia ariniensis* Meléndez and *Passendorferia uptonioides* (Enay), indicating the upper Bifurcatus to lower Hypselum zone interval; (2) *Passendorferia gygii* (Brochwicz-Lewiński et Róžak) and *Orthosphinctes* sp. B, indicating rather confidently the upper Hypselum to lower Bimammatum zone interval; and (3) *Orthosphinctes* sp. A (in isolation), as well as several specimens from the top of the section closely resembling *Orthosphinctes tiziani* (Oppel) of the Bimammatum Zone.

From an outcrop in a region of the eastern Alborz/northern Binalud Mountains, Seyed-Emami and Schairer (2010, 2011) have described a succession of two ammonite-assemblages which also seem to range from the Bifurcatus-Hypselum zones through the base of the Bimammatum Zone. The lower assemblage (Seyed-Emami, Schairer, 2011) consists of *Perisphinctes (Dichotomoceras) crassus* Enay/*Perisphinctes (Dichotomoceras) bifurcatoides* Enay, *Taramelliceras* aff. *costatum* (Quenstedt), *Ochetoceras semifalcatum* (Oppel), *Ochetoceras* cf. *marantianum* (d'Orbigny), and *Euaspidoceras* cf. *striatocostatum* (Dorn). Considering the stratigraphic ranges of most of the species given it can be assumed this assemblage corresponds to the upper Bifurcatus-lower Hypselum zone interval of the Upper Oxfordian. The upper assemblage (Seyed-Emami, Schairer 2010) includes some similar forms

but the assemblage is significantly different and younger: *T. costatum*, *O. aff. marantianum*, *O. aff. tiziani*, *Praeataxioceras* sp. (microconch), *Epipeltoceras bimammatum* (Quenstedt), *Euaspidoceras* cf. *striatocostatum*, *Physodoceras wulfbachense* Schweigert et Callomon. The occurrence of *E. bimammatum* and *Physodoceras* is indicative of the Bimammatum Zone, and thus corresponds already to lowermost Kimmeridgian as accepted herein.

Oxfordian/Kimmeridgian boundary in other Tethyan and Indo- Pacific areas

Because of current status of the studies related to the recognition of the boundary in Europe, only some areas in the World are discussed below. These include (Fig. 8) the territory of the middle part of the Americas (mostly Cuba and Mexico), the Southern America (Chile and Argentina), and some parts of southern Asia – including western India (Kutch Basin) and Nepal (Spiti Shales).

Middle part of the Americas (Cuba, Mexico): The celebrated Upper Oxfordian ammonite assemblages of western Cuba were studied in detail by Polish geologists in the 1970's (mostly Wierzbowski, 1976; Myczyński, 1976; Kutek *et al.*, 1976, and earlier papers cited therein). The assemblage of closely related perisphinctids grouped around the “Cuban” genera – such as *Vinalesphinctes*, *Cubasphinctes* and so-called “Cuban *Discosphinctes*” with the addition of some oppeliids – *Cubaochetoceras* and *Ochetoceras* along with *Glochiceras*, as well as some *Euaspidoceras*, was correlated with a part of the Transversarium Zone – *i.e.* the uppermost Middle Oxfordian, and a part of the Bifurcatus Zone – *i.e.* the lowermost Upper Oxfordian (Wierzbowski, 1976), or only with the Bifurcatus Zone (Myczyński *et al.*, 1998). The perisphinctid ammonites of the assemblage discussed corresponding to the subfamily Vinalesphinctinae Meléndez et Myczyński are interpreted commonly as forms having their roots in the European subfamily Prosoosphinctinae Głowniak. These forms migrated into the Caribbean province during the Middle and early Late Oxfordian in relation to the opening of a new east-west stretching marine connection between the Mediterranean Tethys and the Central Atlantic area where they developed in partly isolated environments under environmental stress conditions (Meléndez *et al.*, 1988; Olóriz *et al.*, 2003; Głowniak, 2012). **The palaeobiogeographic changes in the Mexixo-Caribbean area resulted also from**

development of a deep sea-way between the proto-Gulf of Mexico and the Central North Atlantic basin already during the Mid-Oxfordian time (e.g. Cobiella-Reguera, Olóriz, 2009).

Younger ammonite assemblages in western Cuba are composed almost entirely of aspidoceratids. Two directly following assemblages in the succession may be distinguished (Myczyński, 1976; see also Myczyński *et al.*, 1998): a lower one dominated by *Euaspidoceras* and *Mirosphinctes*, and an upper one composed mostly of *Cubaspidoceras* and *Mirosphinctes*. Additionally there occur some oppeliids – *Ochetoceras* and *Glochiceras*, and very rare perisphinctids. Considering a possible derivation of the ammonite assemblages from the Tethyan ones, it should be noticed that the ammonites of the genus *Epipeltoceras* (as well as their possible dimorphic counterparts - *Clambites* and some related *Euaspidoceras*, see Bonot *et al.*, 2009; Wierzbowski A., Matyja, 2014 b) are for palaeoecological reasons absent in Cuba (as well as in other extra-European areas). The obvious consequence of such an interpretation is that the Cuban *Euaspidoceras* and following *Cubaspidoceras* (macroconchs) with related *Mirosphinctes* (microconchs) represent a separate phylogenetic lineage from that of European *Clambites* and *Epipeltoceras*. The lineage of ammonites *Euaspidoceras* and *Neaspidoceras* (similar and related to *Cubaspidoceras* – which possibly represent highly specialized segment of the lineage) but mostly without *Mirosphinctes* from the Hypselum Zone in Europe (although some ammonites of this genus are reported from Spain and Portugal – see Myczyński *et al.*, 1998, and earlier papers cited therein) may be thus treated as a possible counterpart of the Cuban lineage in question. According to observations from the European sections given above it may be concluded that a lower Cuban ammonite assemblage dominated by *Euaspidoceras* may be correlated with the similar assemblage in Europe recognized in a lower part of the Hypselum Zone; on the other hand an upper assemblage with *Cubaspidoceras* may be correlated with the assemblage with common *Neaspidoceras* occurring in the middle and upper parts of the Hypselum Zone. It should be also remembered that the Cuban perisphinctid referred to as *Perisphinctes* (? *Otosphinctes*) *wierzbowskii* by Myczyński (1976, pl. 11: 6ab) seems very close to an early representative of the genus *Praeataxioceras* which is transitional to an older passendorferiid genus *Graefenbergites* as described by Wierzbowski A. and Matyja (2014 b, pl. 7: 5; see also similar form illustrated by Bonnot *et al.* 2009, pl. 1:7a,b) from the middle part of the Hypselum Zone in Europe.

The youngest ammonite found in the Cuban succession well above the youngest *Mirosphinctes* is an oppeliid of the genus *Metahaploceras* (Myczyński, 1994, pl.1: 4-6; Myczyński *et al.*, 1998) which indicates the presence of the Bimammatum Zone, *i.e.* the

lowermost Kimmeridgian according to the subdivision accepted. This ammonite occurrence precedes the appearance of a sedimentary breccia and subsequent shallow-carbonate deposits in the Jurassic succession of western Cuba interpreted as a consequence of tectonic uplifts at the Oxfordian/Kimmeridgian transition (Pszczółkowski, 1999; Cobiella-Reguera, Olóriz, 2009, with earlier papers cited therein).

The ammonite assemblages of the Upper Oxfordian and lowermost Kimmeridgian in Mexico were discussed recently by Villaseñor *et al.* (2012, with earlier papers cited therein). Several ammonite assemblages can be distinguished in central-east Mexico including that with *Vinalephinctes* attributed to the Bifurcatus Zone, as well as the directly younger one with *Euaspidoceras* and *Praeataxioceras* attributed to a lower part of the Bimammatum Zone *sensu lato*, *i.e.* corresponding mostly to the Hypselum Zone (after López-Palomino in Villaseñor *et al.*, 2012). The occurrence of *Praeataxioceras* together with *Metahaploceras* in the Sierra Madre sections indicates already the Bimammatum Zone and possibly the Planula Zone of the lowermost Kimmeridgian (Myczyński *et al.*, 1998). The youngest ammonites recorded in carbonates of the Zuolaga Group in Mexico, similarly as their lateral equivalents in southern United States (Smackover Fm., and its lateral equivalents) indicate thus the presence of the Bimammatum Zone, and locally even possibly upper part of the Bimammatum Zone – a lower part of the Planula Zone (Olóriz *et al.*, 2003; Villaseñor *et al.*, 2012).

A widespread regional unconformity occurs across the northern rim of the Gulf of Mexico, at the top of the discussed deposits of the shallow system track. The overlying deposits are mixed carbonate-fine siliciclastic rhythmites which yielded ammonites of the upper Platynota to lower Hypselocyclum zones of the Lower Kimmeridgian. These data indicate that the hiatal deposition and erosion prevailed during shallowing trends at the Oxfordian-Kimmeridgian transition over wide areas of Cuba, the north-central Mexico and the northern rim of the Mexican Gulf basin (Olóriz *et al.*, 2003; Cobiella-Reguera, Olóriz, 2009).

Southern America (Chile and Argentina): Several ammonite assemblages from the Oxfordian of northern Chile were described by Gygi and Hillebrandt (1991). The assemblages with *Gregoryceras* corresponding to the Transversarium Zone and lowermost Bifurcatus Zone contains in its upper part also some representatives of *Vinalesphinctes* as well as *Perisphinctes* (*Dichotomoceras*) and forms referred to as *Subdiscosphinctes* - closely

comparable with “Cuban *Discosphinctes*”. The younger assemblage is composed dominantly of aspidoceratids (*Euaspidoceras*, *Cubaspidoceras*, *Mirosphinctes*) and possibly *Praeataxioceras* (see Myczyński *et al.*, 1998) indicating the presence of the Hypselum Zone. Still higher there occur perisphinctid ammonites attributed to such European genera/subgenera as *Orthosphinctes*- *Lithacosphinctes*, including also a form referred to as “*Idoceras cf. neogaeum* Burckardt” by Gygi and Hillebrandt (1991) which is possibly *Geyssantia* according to Myczyński *et al.* (1998). This assemblage may be thus attributed to the Bimammatum Zone, *i.e.* to the lowermost Kimmeridgian (cf. Meléndez, 1989; Myczyński *et al.*, 1998).

Relevant ammonite assemblages have been described recently by Parent (2006) from the Neuquén-Mendoza basin of Argentina. The stratigraphical interval correlated with the upper Bifurcatus – lower Bimammatum (*i.e.* the Hypselum Zone) yielded fairly common aspidoceratids: *Euaspidoceras* with its corresponding microconch *Mirosphinctes* and it corresponds to the Tarapacaenense Zone. The younger assemblage dominated by ammonites compared to the *Orthosphinctes* – *Lithacosphinctes* group corresponds to the Desertorum Zone, and is correlated with the Bimammatum and Planula zones (see Parent, 2006, and earlier papers cited therein), *i.e.* the lowermost Kimmeridgian according to classification accepted herein. Several of the studied sections of the Neuquén-Mendoza Basin yielded also some ammonites attributed to the subfamily Vinalesphinctinae and referred to as *Vinalesphinctes*, *Subvinalesphinctes* and *Cubaspinctes* occurring already in Lower Oxfordian deposits. This observation differs markedly from the distribution of these genera in other areas of the Americas – mostly in the Cuban-Mexico areas where they are known from much younger deposits. According to Parent and Garrido (2015, p. 212) this observation strongly suggests that the Vinalesphinctinae “originated in the Andean region, expanded through the Caribbean (Cuba and Mexico) region during the early Middle Oxfordian, and developed up to the Late Middle Oxfordian in both domains”. This hypothesis is in contradiction with those of Meléndez *et al.* (1988) and Głowniak (2012), as shown above, and additional studies should be undertaken to solve this problem..

Western India: The recent studies in the Kachchh Basin yielded new observations on the ammonite succession at the Oxfordian/Kimmeridgian boundary. The ammonites of the Upper Oxfordian are especially common in the Bifurcatus Zone – mostly its lower part (Stenocycloides Subzone) where numerous specimens of *Perisphinctes* – especially of the subgenus *Dichotomoceras*, many of them close to the European forms, are encountered

(Pandey *et al.*, 2012, with earlier papers cited therein). Ammonites from the upper part of the zone (the Grossouvrei Subzone) are definitely less common, and the general stratigraphical hiatus covering the uppermost Oxfordian and a large part of the Lower Kimmeridgian is present in the large areas of the Katchchh Basin (Pandey *et al.*, 2013, with earlier papers cited therein). The only area where this stratigraphical gap is the smallest is north-eastern part of the basin –the so called Wagad Uplift. The study in that area (Rai *et al.*, 2015) based on nannofossils and dinoflagellate cysts also suggests the condensation and reworking in the stratigraphical interval at the Oxfordian/Kimmeridgian transition. The discussed stratigraphical gaps in the Katchchh Basin may be related with one of the episodes of rifting during formation of the Malgasy Gulf related to break up of Gondawana, possibly responsible also for changes in temperature of sea-water (Alberti *et al.*, 2012).

Nepal (Spiti Shales): The new studies of the ammonite faunas from the Thakkola area in central Nepal showed the presence of a few specimens of aspidoceratid species which could be important for wider correlations. These include: *Neaspidoceras* cf. *tietzei* (Neumayr) together with *Perisphinctes* (*Perisphinctes*) of early Late Oxfordian age (in beds with mayaitids), and along with Indo-SW Pacific perisphinctids (*Sulaites*, *Praekossmatia*). The overlying assemblage with *Parabolicseras* (and the last mayaitids) yielded in its lower part form referred to as *Clambites* sp. indet./ cf. *spathi* Collignon which suggests an Early Kimmeridgian age (see Enay, 2009). These data shed some light on the stratigraphical correlation between the “classical” Mediterranean ammonite faunas and those of Indo-SW Pacific areas (Enay, Cariou, 1997).

Climatic and environmental changes at the Oxfordian/Kimmeridgian transition

The general changes in climatic/environmental conditions at the Oxfordian/Kimmeridgian transition have been the subject of several palaeontological and geochemical papers published recently. The comments given below mostly relate to the European areas.

Abbink *et al.* (2001) analyzed the sporomorph assemblages from bore-holes of the southern North Sea, *i.e.* from the area generally corresponding to the Subboreal-Boreal province transition. They showed that the general trend of aridification and warming of the

climate which had begun in the Middle Oxfordian was “briefly interrupted in the latest Oxfordian-earliest Kimmeridgian interval by a cooling” especially well pronounced during the late Regulare and Rosenkrantzi chrons of the latest Oxfordian, and successively followed by a warming near the Oxfordian/Kimmeridgian boundary (Abbink *et al.*, 2001, p. 241, fig. 12) .

The changes in composition of the ammonite and microfossil faunas in the bore-holes of the Peri-Baltic Syncline in northern Poland show the mixed character of the assemblages corresponding to the uppermost Oxfordian and lowermost Kimmeridgian (Wierzbowski *et al.*, 2015, figs 10-11). The uppermost Oxfordian (Rosenkrantzi-Hypselum and Pseudocordata zones) is characterized by a marked increase in the number of Boreal ammonites interpreted as a renewal of the Boreal Spread reported from below in the Lower and lowermost part of the Middle Oxfordian; on the other hand, the lowermost Kimmeridgian is characterized by a dominance of the Subboreal ammonites.

These changes in faunal assemblages in the northern European areas are well correlated with changes in the depositional environments. The latest Oxfordian marked the decline of shallow-water carbonate and sandy deposits of the British Corallian, whereas the beginning of the Kimmeridgian showed the appearance of a younger Pomerania shallow water carbonate platform. It seems highly probable that the changes in environmental conditions were stimulated to some degree by the tectonic movements which took part at the Oxfordian/Kimmeridgian in wide areas of northern Europe. These phenomena are reported from the North Sea through the Danish Basin and the Fennoscandian Border Zone of southern Scandinavia, the peri-Baltic Syncline, and possibly even more eastwards up to the northern edge of the Russian Platform – the Timan-Pechora Basin (Wierzbowski A. *et al.*, 2015 with earlier papers cited therein). The related stratigraphic unconformity is also interpreted in terms of the sequence-stratigraphical scheme, and the tectonic phenomena discussed stimulated the changes in the Subboreal ammonite (Aulacostephanidae) lineage resulting in the appearance of two separate branches – that of *Pictonia* in NW Europe, and another of *Vineta* and *Vielunia* in NE Europe (see Enay, 1980; Wierzbowski A., 2010 a; Wierzbowski A. *et al.*, 2015, and earlier papers cited therein).

Seawater paleotemperatures, and variations in carbon isotope composition in the Middle Russian Sea and in the peri-Tethyan basins of central Europe, corresponding mostly to the Submediterranean province, were discussed recently by Wierzbowski H. *et al.* (2013) and

Wierzbowski H. (2015). The $\delta^{18}\text{O}$ values of belemnite rostra and brachiopod shells decrease from the top of the Middle Oxfordian up to the Early Kimmeridgian. The decrease may have resulted from an increase in sea-water temperature and local effects related to the shallowing of the studied basins. The data obtained from the central European basins are, however, especially scattered in the uppermost Oxfordian (uppermost Bifurcatus Zone and the Hypselum Zone – up to the boundary with the Kimmeridgian) – which may suggest unstable environmental conditions in those times. Despite the effect of local bathymetry changes and salinity variations, the isotope studies show a world-wide long-term warming trend during the Late Oxfordian–Early Kimmeridgian, which is observed not only in various European basins but also in Arctic and Indo – Malgasian basins (cf. Zakharov *et al.* 2005; Nunn *et al.*, 2009; Žak *et al.*, 2011; Alberti *et al.* 2012; Arabas, 2016 in press).

The $\delta^{13}\text{C}$ values of marine carbonate fossils from the peri-Tethyan sections show a general decrease subsequent to the Middle Oxfordian, and the lowest carbon isotope values correspond to the stratigraphical interval of the uppermost Oxfordian from the uppermost part of the Bifurcatus Zone and in the Hypselum Zone. The data may show the high level of nutrients and increased productivity of sea water at the Oxfordian–Kimmeridgian transition in the studied peri-Tethyan basins (Wierzbowski H., 2015, figs 9-10). **Broadly similar trends of decreasing carbon isotope values at the Oxfordian–Kimmeridgian boundary are reported from Boreal and Mediterranean sections of Europe, although the absolute $\delta^{13}\text{C}$ values of marine carbonates vary probably because of changes in chemistry of local seawater and the various origin of studied carbonates (Bartolini *et al.*, 1996; Morettini *et al.*, 2002; Nunn *et al.*, 2009; Wierzbowski *et al.*, 2013; Coimbra *et al.*, 2014; Jach *et al.*, 2014; Arabas, 2016, in press).**

Detailed studies of the uppermost Oxfordian deposits (Hypselum Zone) and the lowermost Kimmeridgian in two sections (Katarowa Góra and Bobrowniki) in the Wieluń Upland in central Poland make possible the correlation between the long-term and short-term fluctuations in the faunal assemblages and in the magnetic and the geochemical data (presented by Grabowski *et al.*, 2015; Wierzbowski A. *et al.*, 2015 b, during the 2nd International Congress on Stratigraphy, Graz, July 2015, but the whole results will be given elsewhere). The deposits studied consist of bedded limestones and marls of the sponge megafacies of the deep neritic northern Tethyan shelf (Fig. 1). The ammonite faunas occurring here are mostly of Submediterranean character, but Boreal ammonites (Cardioceratidae: *Amoeboceras*) and bivalves (*Buchia*) as well as the Subboreal ammonites

(Aulacostephanidae) become quite common at some levels (Fig 9AB). Longer term, as well as shorter term, variations in the faunistic assemblages may be recognized –the former are especially well visible – and are discussed below. A prominent maximum of occurrence of the colder-water Boreal-Subboreal faunas is observed in the middle of a lower part of the succession (about 6-7 meters thick) of the Hypselum Zone of the uppermost Oxfordian in the Katarowa Góra section of the Wieluń Upland– around the “*Amoeboceras* layer” (containing over 70% Boreal cardioceratids) – see Fig.96A and Fig. 10 (interval I). Another interval similar in thickness displaying an increase (but a weaker one) in the number of Boreal-Subboreal faunal elements is recognized in the upper part of the Hypselum Zone (interval II in Fig. 10). The older deposits corresponding to the upper part of the Bifurcatus Zone of the Upper Oxfordian show another marked increase in Boreal *Amoeboceras* ammonites (Wierzbowski A., Matyja, 2014 b; see also Fig.9A). The deposits of the Hypselum Zone studied in the Wieluń Upland show the occurrence of radiolarian faunas – mostly of the Tethyan origin – but representatives of the Boreal *Paravicingula* assemblage do occur in the “*Amoeboceras* layer”.

The occurrence of Boreal-Subboreal ammonite assemblages in the Hypselum Zone of the uppermost Oxfordian could be related to activity of the sea-currents which additionally brought nutrient-rich waters which enabled the development of the radiolarian assemblages. The action of sea currents along the existing sea-ways between the northern and southern areas of Europe may have been stimulated by the contrasted climate changes during the latest Oxfordian. The content of non-carbonate material in the studied sections of the Wieluń Upland is very low. The content of Al and Rb typically varies between 0.04 – 0.15%. and 0.5 – 2 ppm respectively (Fig .10). A relatively higher input of terrigenous material is observed only in the intervals rich in Boreal and Subboreal ammonites (*e.g.* the “*Amoeboceras* layer”) which occur in the lower and upper part of the Hypselum Zone (intervals I and II in Fig. 10). These intervals reveal also relatively higher values of the anhysteretic remanent magnetization (ARM – proxy of fine grained magnetite of presumably detrital origin) as well as the Th/U and P/Al ratios, which points to oxic conditions of the bottom water and increased accumulation of biogenic phosphorus, most probably related to enhanced productivity. These geochemical observations are in good agreement with the palaeoecological observations.

A marked change in faunal assemblages is observed in the upper part of the succession of the Wieluń Upland (Bobrowniki section) – in the lowermost Kimmeridgian (Bimammatum Zone). It corresponds to the decline of colder-water Boreal-Subboreal faunas, and the

dominance of warmer-water Submediterranean ammonites (Oppeliidae) (see Fig. 9B). Their dominance follows mostly a well developed, tectonically enhanced omission surface (interval III in the Fig. 10) – which is recognized at the Oxfordian/Kimmeridgian boundary over vast areas of northern Europe – delimiting there two environmentally contrasted faunal assemblages. The dominant oppeliids are mostly small-sized necto-pelagic forms whose occurrence along with the Tethyan radiolarians indicates the presence of nutrient-rich waters. Within the discussed part of the Wieluń Upland succession a gradual decrease in detrital influx is observed, which is broken temporary only at the Oxfordian/Kimmeridgian boundary represented by the omission surface, showing an extremely high content of terrigenous elements and magnetic minerals. The discussed upper part of the succession (interval IV in the Fig. 10) is characterized however by generally lower values of magnetic indexes and stepwise oxygen depletion of bottom water (decrease of Th/U ratio), when compared with its lower, uppermost Oxfordian part. The productivity index (P/Al) reveals here higher variations and attains its maximum values. These phenomena might be related to a diminished mixing of seawater and an increased in carbonate production either as a result of the long term warming trend, which is documented on the basis of belemnite $\delta^{18}\text{O}$ ratios, or the local shallowing of the Polish Jura basin. The abrupt changes in ammonite assemblages are, however, not mirrored in variations in the $\delta^{18}\text{O}$ values of necto-benthic belemnite rostra and benthic brachiopod shells, although the discussed intervals are characterized by scattered $\delta^{18}\text{O}$ values, which may show an environmental instability (*cf.* Wierzbowski H., 2015).

Geochemical screening study of Upper Jurassic bulk carbonates in western Tethys shows, the existence of long-term cycles related to sea level fluctuations, which is contrary to high-amplitude variations known from epicontinental deposits (Coimbra *et al.*, 2015).

Summarizing the observations given – the transition from the Oxfordian to the Kimmeridgian (corresponding to the boundary accepted herein) showed marked climatic and environmental fluctuations as observed in the vast areas of the Boreal-Subboreal and the Submediterranean basins in Europe and the adjoining Arctic basins. Very unstable conditions of the latest Oxfordian (Pseudocordata-Rosenkrantzi-Hypselum chrons) may have resulted from changes in sea-current activity and short-term cooling of the sea water (possibly in several successive episodes) in some marine basins. The tectonic phenomena additionally modified the palaeogeography in northern Europe (Subboreal Province) at the Oxfordian/Kimmeridgian boundary and possibly stimulated the climatic changes. A general warming trend observed in the earliest Kimmeridgian (Baylei-Bauhini-Bimammatum chrons)

both in the Submediterranean province, but also in the Subboreal-Boreal provinces, has been well proved by stable isotopes and palaeontological data (e.g. Abbink *et al.*, 2001; Nunn *et al.*, 2009; Wierzbowski H. *et al.*, 2013; Wierzbowski A. *et al.*, 2015 a; Wierzbowski H., 2015). A good example of the latter is the spectacular appearance of small-sized *Plasmatites* at the base of the Boreal Kimmeridgian over wide areas (including the “deep” Arctic) possibly representing the mature paedomorphic (neotenic) forms whose occurrence has been most probably controlled by the environmental factors (Wierzbowski A., Rogov, 2013).

The climatic and environmental fluctuations during latest Oxfordian – earliest Kimmeridgian resulted also in changes of the other ammonite groups. The extinction of the genus *Perisphinctes* and the whole subfamily Perisphinctinae in the Submediterranean-Mediterranean provinces, but also in the Indo-Malgasian Province (to the decline of the Mayaitidae), at the Bifurcatus/Hypselum chron transition, can be related to the beginning of such fluctuations. Of a similar character might be the disappearance of ammonites of the subfamily Vinalesphinctinae approximately at the same level in the Andean and Caribbean provinces of the Americas. **These can be also stimulated by the tectonic phenomena – reported from both margins of the Central North Atlantic basin and the Western Tethys (Olóriz *et al.*, 2003, and the references therein), as well as from the Malgasy Gulf of the Indo-Malgasian areas (Alberti *et al.*, 2012, and the references therein).** On the other hand, successive renewal of the ammonite faunas took place during latest Oxfordian, resulting in the appearance of the new ammonite family (Ataxioceratidae) and the new groups of ammonites of the families Aspidoceratidae and Oppeliidae at the transition between the Oxfordian and Kimmeridgian.

Conclusions

The data discussed show that the base of the Subboreal ammonite Baylei Zone (placed at the base of the *flodigarriensis* horizon) and the corresponding base of the Boreal ammonite Bauhini Zone may be correlated with a narrow stratigraphic interval at the boundary of the Hypselum and Bimmmatum ammonite zones of the Submediterranean/Mediterranean succession, and can be treated as a perfect candidate for the Oxfordian/Kimmeridgian boundary, having a large correlation potential. The boundary is defined also by methods other than palaeontological – including the palaeomagnetic, sedimentary, tectonic, climatic and geochemical data. Such a definition of the boundary in question results in its wide correlation potential and means that it can be recognized in the different marine successions of the World.

The changes are likely to be recognized in successions of terrestrial deposits as well. Thus, strongly recommended by us, is the formal recognition of the base of the *flodigarriensis* horizon at the base of the Baylei Zone in the Flodigarry section at Staffin Bay on the Isle of Skye, northern Scotland, as the level and site of Global Stratotype Section and Point (GSSP) for the Oxfordian/Kimmeridgian boundary.

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Explanations to figures

Fig. 1 Location of geological sections discussed in the study placed on a palaeogeographic map of the Middle to Late Oxfordian transition of Europe (after Matyja and Wierzbowski A., 1995): 1- Staffin Bay, Isle of Skye (Flodigarry section); 2- Dorset Coast; 3- Pomerania; 4 – Peri-Baltic Syncline; 5- Poitou area; 6 – Wieluń Upland (Katarowa Góra and Bobrowniki sections); 7 – middle part of Polish Jura (Syborowa Góra and Biskupice sections); 8 –

Franconian Alb; 9 – Swabian Alb; 10 – northern Switzerland Jura; 11 – Pre-Betic Zone (Fuentelspino de Moya section); 12 – South-eastern France.

Fig. 2. Distribution of ammonites in the Flodigarry section, Staffin Bay, Isle of Skye – the proposed GSSP of the Oxfordian and Kimmeridgian boundary, and their chronostratigraphical interpretation (after Matyja *et al.*, 2006, slightly modified); 1-silty clay; 2-concretionary limestone bed; 3-*Pictonia densicostata* rich bed; 4-shaly clay and clay; 5-argillaceous sandstone; 6 –bed number; grey bars are referred to cf. species; grey blocks in chronostratigraphical column indicate the intervals of uncertain correlation.

Fig. 3. Summary magnetostratigraphic data across the Oxfordian-Kimmeridgian boundary at Flodigarry, showing the previous and new (in green) data sets. The virtual geomagnetic palaeopole (VGP) was used to determine the VGP latitude (VGP latitude -90 to 0= reverse polarity; 0 to +90 = normal). Declination, Inclinations are the directions of tilt-corrected specimen characteristic remanence, and show north directed (south), positive (negative) inclination for normal (reverse) polarity. Polarity rating is a qualitative evaluation of the interpreted magnetic polarity shown by individual specimens, ranging from 3 (very good) to poor (1). See Przybylski *et al.* (2010) for further information.

Fig. 4. Summary magnetostratigraphic results from other Boreal- Subboreal sections (see Przybylski *et al.* 2010, for section data), the proposed GSSP, and the composite magnetic polarity for these sections.

Fig. 5. Distribution of ammonites in the Polish Jura sections (central Poland) and their chronostratigraphical interpretation (after Wierzbowski A., Matyja, 2014 b, somewhat modified); the lower *Amoeboceras* layer – the local reference horizon - is indicated; dark blue – Oxfordian, light blue – Kimmeridgian.

Fig. 6. Some newly collected ammonites and bivalves from the Bobrowniki section, Wieluń Upland, central Poland (1-6, cf. Fig. 5) and from Russian Platform (Moscow area), northern Siberia and Franz-Josef Land (Wilczek Land), Russia (7-12):

1ab – *Ochetoceras marantianum* (d'Orbigny), both sides of a large, fully grown specimen, MUZ PIG 1797.II.126, bed D, Berrense Subzone, Hypselum Zone; 2 - *Vineta* sp., lappeted microconch - closely comparable with microconchs illustrated by Wierzbowski *et al.*, 2010 (pl. 6: 6-7), MUZ PIG 1797.II.100, bed C - uppermost part, at the boundary of the Oxfordian and Kimmeridgian; 3 – aulacostephanid (? *Vineta* sp), macroconch, fragment of the inner

whorls of the phragmocone, MUZ PIG 1797.II.118, bed C- uppermost part, at the boundary of the Oxfordian and Kimmeridgian; 4 – *aulacostephanid* (?*Vineta* sp), macroconch, fragment of the body chamber, MUZ PIG 1797.II.122, bed B – lowermost part, lowermost Kimmeridgian; 5 – *Microbiplices* – *Prorasenia* trans.form, MUZ PIG 1797.II.100, bed C, uppermost Oxfordian; 6 – *Buchia concentrica* (Sowerby), MUZ PIG 1797.II.112, bed C, uppermost Oxfordian; the phragmocone/body chamber boundary is arrowed;

7 ab – *Amoeboceras (Plasmatites) zietenii* (Roullier), lateral and ventral side, specimen illustrated by Nikitin (1916, pl. 2: 12), Mnevniky (Moscow), CNIGR Museum, col. 29/5247; 8 ab – a. *Amoeboceras (Plasmatites) zietenii* (Roullier) transitional to *A. (P.) gerassimovi* Mesezhnikov, Kalacheva et Rotkyte, b. *Prorasenia* sp., Lipitsy (Kaluga region near Moscow), MK 4761, Geological Institute, Russian Academy of Sciences (RAS), Bauhini Zone – lowermost part; 9 ab – *Amoeboceras (Plasmatites) praebauhini* (Salfeld), lateral and ventral view, Levaya Boyarka, MK 6970, Geological Institute, Russian Academy of Sciences (RAS), rubble; 10 – *Amoeboceras rosenkrantzi* Spath, Wilczek Land, MK 6843, Geological Institute, Russian Academy of Sciences (RAS); 11 – *Amoeboceras (Plasmatites)* sp. – ventral side, MK – 6848, Geological Institute of RAS; 12 – *Amoeboceras (Plasmatites)* spp., MK 6837, Geological Institute of RAS ; all specimens natural size.

Fig. 7. Correlation of the Submediterranean zonal scheme with the Subboreal and Boreal zonal schemes around the Oxfordian/Kimmeridgian boundary (after Wierzbowski A., Matyja, 2014 a,b; slightly modified by Matyja and Wierzbowski, herein): white blocks indicate the intervals of uncertain correlations; dark blue – Oxfordian, light blue – Kimmeridgian.

Fig. 8. Location of geological sections outside central and western Europe discussed in the study placed on a global plate tectonic map of the latest Middle Jurassic to Late Jurassic (after Golonka, 2000, simplified), gray – continents – landmass and shallow seas; dark blue – deep ocean basins: 1 – Russian Platform (central part); 2 – northern central Siberia (Taimyr peninsula and Nordvik peninsula); 3 – Franz-Josef Land; 4 – southwestern Barents Sea; 5 – northeastern Norwegian Sea; 6 – Cuba; 7 – Central-east Mexico; 8 – northern Chile; 9 – Argentina: Neuquén – Mendoza basin; 10 – northern Iran; 11 – western India; 12 – Nepal.

Fig. 9. Frequencies of occurrence of ammonites in the uppermost Oxfordian and lowermost Kimmeridgian in the sections of the Polish Jura (central Poland) studied: A. uppermost Oxfordian at Syborowa Góra, Biskupice and Katarowa sections ; B – uppermost Oxfordian and lowermost Kimmeridgian at Bobrowniki section (omission surface at the

Oxfordian/Kimmeridgian boundary is shown in red); ammonite groups and their palaeogeographic position: red – Mediterranean and Submediterranean (Ph – Phylloceratidae, P-Perisphinctidae, At-Ataxioceratidae and Passendorferiinae, As-Aspidoceratidae, O – Oppeliidae); green – Subboreal (Au-Aulcostephanidae); blue – Boreal (C - Cardioceratidae); mode of life: gray – benthic (perisphinctids and aulacostephanids); brown – necto-benthic (heavy-ornamented Oppeliidae, Cardioceratidae); yellow – necto-pelagic (Phylloceratidae, small Oppeliidae: *Richeiceras*, *Metahaploceras*, *Coryceras*), white – necto-benthic and/or necto-pelagic.

Fig. 10. Selected magnetic and geochemical element data from the Katarowa Góra and Bobrowniki sections (Wieluń Upland, central Poland) representing the stratigraphical interval at the Oxfordian/Kimmeridgian boundary (the Hypselum Zone – the Bimammatum Zone interval): anhysteretic remanent magnetization (ARM), Rb, Th/U and P/Al.

ARM is a rock magnetic proxy for the presence of fine grained magnetite (most probably of detrital origin). Rb is a lithogenic element very well correlated with Al ($r = 0.95$), quantifying detrital input in the sections. Th/U ratio is applied as a redox sensitive parameter, while the P/Al ratio reflects changes in biogenic phosphorus accumulation related to productivity changes. I, II, III, IV – characteristic intervals of environmental change. Grey stripes: marly limestone horizons where there is the common occurrence of Boreal and Subboreal ammonite species. Note the long term decrease of detrital input and deterioration in oxic conditions. Intervals I and II represent periods of frequent excursion of Boreal and Subboreal ammonites, marked by increased detrital input (maxima of ARM, Rb) and relatively better bottom water oxygenation, manifested by peaks of the Th/U ratio. Most of the peaks correlate with increased productivity proxies (P/Al). Interval III contains the omission surface related to the very large increase of detrital proxies and maximum Th/U ratio. Interval IV is dominated by extremely low detrital input, poor oxygenation of bottom water and large increase of biogenic productivity shown by the common occurrence of small necto-pelagic Oppeliidae.