Proposal for the Thuoux section as a candidate for the GSSP of the base of the Oxfordian stage

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Abstract: The Thuoux section, located in South-Eastern Basin of France (coordinates: 44°30'55"E; 5°42'25"N), is a section that satisfies numerous demanding criteria as a reference section (GSSP) for the base of the Oxfordian stage. Sedimentation was continuous in that the abundant ammonitic fauna yields no detectable hiatuses. The stratigraphic boundary is located between the Lamberti Zone and the Mariæ Zone or more precisely between the Paucicostatum horizon (MARCHAND, 1979) and the Thuouxensis horizon (FORTWENGLER & MARCHAND, 1994a). In this section, there is a perfect mixing between Boreal ammonites (Cardioceratinae) whose species are used as stratigraphic markers and Sub-mediterranean/Subboreal ammonites (Hecticoceratinae, Peltoceratinae and Perisphinctinae) that provide further possibilities for wide correlation of this boundary. Finally, parallel ammonite zonations have been established with great precision (biohorizons and sometimes "sub-biohorizons") in various areas of France, with different palaeoenvironments. The Thuoux section permits correlations with central and eastern Europe as well as North America, based on Cardioceratinae successions, and with South America, using Peltoceratinae. Thickness of the Callovian-Oxfordian transitional beds in the Thuoux section has allowed detailed sedimentological studies and astronomical calibration of the Lower Oxfordian (BOULILA, 2008; BOULILA et al., 2008). The Thuoux section is located at the centre of a set of more than thirty sections where the base of the Oxfordian stage is visible (FORTWENGLER, 1989; FORTWENGLER & MARCHAND, 1994a, b, c, d).

Key Words: Ammonites; upper Callovian; lower Oxfordian; GSSP Oxfordian.

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Résumé : Proposition de candidature de la coupe de Thuoux (France) pour le GSSP de la base de l’étage Oxfordien.- La coupe de Thuoux, localisée en France dans le Bassin du Sud-Est, (coordonnées : 44°30'55"E; 5°42'25"N) satisfait à la majorité des critères demandés pour devenir le GSSP de la base de l’étage Oxfordien. La sédimentation est continue à l’échelle de l’horizon ammoniti-que et en particulier des horizons à Paucicostatum (MARCHAND, 1979) et à Thuouxensis (FORTWENGLER & MARCHAND, 1994a). Dans cette coupe, il y a un mélange constant entre les ammonites boréales (Car- dioceratinae) et les ammonites subboréales et sub-méditérranéennes (Hecticoceratinae, Peltoceratinae et Perisphinctinae) ce qui autorise de larges corrélations géographiques. De plus, la présence simulta-
née de ces 4 sous-familles permet un découpage temporel très précis et permet aussi de proposer des corrélations temporelles entre l’Europe Occidentale, le nord de l’Amérique (grâce aux Cardioceratinae) et l’Amérique du Sud (grâce aux Peltothecata). La forte épaisseur des sédiments à Thuoux a aussi permis des études sédimentologiques et une calibration astronomique de l’Oxfordien inférieur (BOULILA, 2008 ; BOULILA et al., 2008). Enfin, plus d’une trentaine de coupes ont été analysées en détail autour de Thuoux, ce qui augmente la fiabilité des résultats obtenus sur la coupe où la base de l’Oxfordien est visible (FORTWENGLER, 1989 ; FORTWENGLER & MARCHAND, 1994a, b, c, d).

Mots-Clefs : Ammonites ; Callovien supérieur ; Oxfordien inférieur ; GSSP Oxfordien.

1. Introduction

The Thuoux and Savournon sections were proposed as candidates for Global Boundary Stratotype Section and Point (GSSP) of the Oxfordian Stage more than 15 years ago (FORTWENGLER & MARCHAND, 1994a, b, c, d). Both these sections were assessed as excellent in so much as in 1996 (in MELÉNDEZ) a vote by Oxfordian Working Group yielded the following results:

- Thuoux - Savournon (France) - 24 votes
- Redcliff Point (England) - 5 votes
- another locality to be studied - 1 vote

Subsequently, we have focused our efforts on the Thuoux section which is located about 600m N-E from Thuoux (close to Aspremont and Saint-Pierre-d’Argençon), 5km west of Aspres and 7km north of Serres (Département des Hautes-Alpes, France). Coordinates: 44°30' 55"E; 5°42'25"N (Figs. 1-2).

The Thuoux section, in contrast to Savournon, is not disturbed by faults and provides easier recognition of the units described below. Moreover, the gentler slope of the Thuoux section precludes strong mixing of faunas as well as pollution of the section by elements coming from the upper layers.

MELÉNDEZ (2004, 2006) expressed doubts about choosing Thuoux "because of preservation of ammonites as pyritic nuclei" or "the poor state of preservation of ammonites, as small pyritic nuclei, making them difficult to interpret". As a consequence, in the table p. 18 of MELÉNDEZ (2006), ammonites from Redcliff are assessed (5) against Thuoux (1). This is surprising as Thuoux and Savournon ammonites are preserved in a virtually identical way (FORTWENGLER & MARCHAND, 1994c, d). At both Thuoux and Savournon, the fossils are carbonate internal moulds corresponding either to the phragmocone alone, or including part or all of the body chamber. Never are the ammonites pyritic. In both sections, the average diameter of ammonites is about 5 cm.

**Figure 1:** Location of the Thuoux section proposed as GSSP Oxfordian.
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**Figure 2:** The Thuoux section with the position of the Callovian / Oxfordian boundary (C: Callovian and O: Oxfordian).
### 2. Description of the Thuoux section proposed as the GSSP of Oxfordian stage

In the South-Eastern Basin of France a very thick marly limestone series bearing white and carbonate nodules crops out. The succession is known under the name of "Terres Noires", a term which also denotes its facies. This unit ranges from upper Bajocian to middle Oxfordian (Antecedens Subzone). At the Thuoux section, the stratigraphic interval from the upper Callovian (Lamberti Zone, Lamberti Subzone) to the lower Oxfordian (Mariae Zone, uppermost Praecordatum Subzone) is well preserved and almost 200m in thickness (Fig. 3).

This study was initiated by Fortwengler during the 1980s, resulting in 1989 in the first publication in which detailed biostratigraphical framework was later updated (Fortwengler & Marchand, 1994a; Fortwengler et al., 1997) and officially accepted by the Groupe Français d'Étude du Jurassique (Carriou et al., 1997). At present, it is accepted by all Western European colleagues and notably by Chapman in Weymouth (1996, 1997, 1999) and Jardat (2010) in the French Jura. After more than 25 years' research, the Callovian/Oxfordian transition has been observed in the South-Eastern Basin in 61 sections (Fig. 4), and in thirty of them exhaustive in situ collection of ammonites has been carried out, in order to determine precisely the limits of every horizon to analyse the ammonite populations (Fortwengler, 1989; Marchand et al., 1990; Fortwengler et al., 1997). More than 5,000 ammonites were collected close to the upper Callovian/lower Oxfordian boundary. It is particularly important to note that in all these collections, from all levels, Phylloceratidae and especially Sowerbyceras, are always present and abundant.

At the levels 5B, 6A-6B, 7 and 8A (field numbers) which correspond to the Callovian/Oxfordian transition (Fortwengler, 1989), ammonitids are more abundant than phylloceratids, whereas from levels 8B/9 (uppermost Scarburgense biohorizon and lowermost Woodhamense biohorizon) we record the reverse. The latter is interpreted as due to the occurrence of extensional tectonics correlated with deepe-
ning and so with increase of phylloceratids. This phenomenon is known from numerous regions of Western Europe (Marchand, 1986).

Faunal comparisons were effected between the Boreal and Tethyan provinces, thanks to very precise collections made on the Isle of Skye (Turner, 1963; Sykes, 1975; Morton & Hudson, 1995) and around Nice (Dardeau & Marchand, 1979), and in between in Yorkshire, Dorset, the margins and centre of Paris Basin (Agence nationale pour la gestion des déchets radioactifs, ANDRA drillings), the Jura, the South-Eastern Basin of France, and several European countries (Germany, Bulgaria, Poland and Rumania with the help of colleagues in these countries).

Among all the Western European sections (see references), the Thuoux section is clearly the most accessible, the most interesting and the most reliable. It begins with upper Callovian (Lamberti Zone) and ends with lower Oxfordian (slightly below the Mariae Zone/Cordatum Zone boundary) deposits. This stratigraphic interval is continuous and, quite rarely for the “Terres Noires”, free of faults. Moreover, sedimentary layers are sub-vertical, which makes thickness measurements easy. The occurrence of thin, slightly more carbonate-rich levels leads, through differential erosion, to smooth recesses which facilitate the collecting of ammonites in situ. There are also reddish carbonate intervals and concentrations of aligned grey to ochre nodules that constitute highly visible and very reliable markers. In these sections, ammonites are frequent, and commonly of greater size than in Savournon, with shell diameter above 10 cm. Counts made by D.F. and D.M on their collections from Thuoux are as follows (Fortwengler & Marchand, 1994d):

- Level 5B (Lamberti horizon): n = 98
- Level 6A (lower part of Paucicostatum horizon): n = 148
- Level 6B (upper part of Paucicostatum horizon): n = 156
- Level 7A (lower part of Thuouxensis horizon): n = 175
- Level 7B (upper part of Thuouxensis horizon): n = 30
- Level 8A (lower part of Scarburgense horizon): n = 345
- Level 8B (lower part of Scarburgense horizon): n = 172
- Level 9 (upper Scarburgense / lower Woodhamense horizon): ammonites are rare.

Collectéd macro-invertebrates are low in diversity as ammonites frequently reach 100% of the macrofauna. Other cephalopods are present but belemnite rostra and rhyncholites are scarce, and nautilids extremely rare. Bivalves are not frequent although sometimes they are concentrated inside ammonite body chambers (levels 7B and 9). Brachiopods and echinoderms are totally absent at Thuoux. And what is true at Thuoux is true within all the “Terres Noires” of the Dauphinois Basin.

3. The Callovian-Oxfordian boundary and the fossil record (Figs. 4 - 5)

a. Ammonites (MARCHAND, 1979; FORTWENGLER & MARCHAND, 1994a, b, c, d)

Uppermost Callovian ammonites (Lamberti Zone, Lamberti Subzone, Lamberti and Paucicostatum biohorizons).

- Level 5A (at Thuoux: this level is poorly exposed).
  At other places it always yields ammonites from Praelamberti biohorizon.
- Level 5B (at Thuoux: 8.50m thick).
  The Lamberti biohorizon still yields Callovian genera that are recorded in 5A. Quenstedtoceras is now represented by Q. lamberti (SOWERBY) (Pl. 1: 3) and this is the level where we have found the youngest individual from the genus Kosmoceras (Pl. 1: 4) among quite numerous Pseudoperisphinctinae (Pl. 1: 2). Peltoceratinae are very scarce. We identify the earliest Perisphinctinae (Alligaticeras aff. alligatum) (Pl. 1: 1) with "Oxfordian morphology". Hecticoceratinae are also present (Pl. 1: 5).
- Level 6 (at Thuoux: 16.8m thick).
  The top part of the Lamberti Subzone (Levels 6A and 6B) corresponds to the Paucicostatum biohorizon (MARCHAND, 1979; FORTWENGLER & MARCHAND, 1994a) in which subfamily Cardioceratinae is represented by the rare latest Quenstedtoceras lamberti (SOWERBY) and the first Cardioceras paucicostatum LANGÉ (Pl. 1: 8, 12). In this species, the whorl section is acute-oval, primary ribs are more numerous and less heightened than in Quenstedtoceras lamberti (SOWERBY) and there are only one or two secondary ribs between two primaries (level 6A). C. paucicostatum is very easy to distinguish from Q. lamberti and clearly announces the later Cardioceratinae Cardioceras scarburgense (YOUNG & BIRD) species. That is the reason why we consider it to be the earliest species of genus Cardioceras (see MARCHAND, 1979, 1986).

Note that the genera Kosmoceras and Distichoceeras, clearly present in the last horizon of the Lamberti Subzone (SB), have never been collected in the Paucicostatum horizon (level 6) of Western Europe. Hecticoceratinais (about 50% of fauna) abound but still display "Callovian" morphology (Pl. 1: 6, 7, 9, 11). A quite rare species, Hecticoceras coelatum COQUAND, is characterized by ventral ribs that are continuous around the ventral axis. In contrast, in the specimens of H. coelatum COQUAND, from the Lamberti biohorizon (SB), these ribs never cross the ventral axis. In every French record of this species, transition from one morphology to the other quite reliably indicates the Callovian / Oxfordian boundary.

Within this biohorizon the history of the two important genera also diverges:

- Cardioceratinae's history changes with the appearance of genus Cardioceras (C. paucicostatum LANGÉ) whose successive species are used as biostratigraphic markers up to the end of the mid-Middle Oxfordian;
- Peltoceratinae's history begins to change, slightly later, through the appearance of the first member of Peltoceratoides with P. eugenii (RASPAIL) (Pl. 1: 13, 14), a species with split ventro-lateral tubercles. Successive species will also be of use in the biostratigraphic subdivision of the Lower Oxfordian (BONNOT, 1995; BONNOT et al., 1997, 2002). In the level 6A, Peltoceratoides aff. Shrœderi does not show split tubercles (Pl. 2: 1).

The combination of these two genus lineages (Cardioceras and Peltoceratoides) permit a very precise and reliable biostratigraphy.

All specimens are from D. Fortwengler’s collection. Photos: D. Fortwengler; preparation of plate: Simone Dutour. Red point: end of phragmocone.
Basal Oxfordian ammonites (Mariae Zone, Scarburgense Subzone, Thououxensis, Scarburgense and Woodhamense biohorizons) (Pls. 2 - 3).

- Level 7 (at Thuoux: 13m thick).

"Les Richiers" section, ammonites are characterized by occurrence (up to 30% of fauna), of a distinctive Hecticoceratinae taxon: Hecticoceras (Brightia) thououxensis FORTWENGLER et al. (1997) (Pl. 2: 3, 4, 5). This index species is unknown below (in Paucicostatum horizon) and becomes rare at the base of the Scarburgense biohorizon.

The Thououxensis biohorizon was first described in the South-Eastern Basin, where it was identified in more than 30 sections. Recently it was also described in the Paris Basin from ANDRA drillings (THIERRY et al., 2006). Throughout the Thououxensis biohorizon, the bifurcation points of Peltoceratoides always lie in the upper half of the lateral flank (BONNOT et al., 1997, 2002) (Pl. 2: 7, 8). Further, among Cardioceratinae, the paucicostatum morph remains present and the scarburgense morph (Pl. 2: 2) makes its first appearance.

- Level 8 (at Thuoux: 21.3 m thick).

This level corresponds to the Scarburgense biohorizon. The index species is easy to recognize (Pl. 2: 10-11; Pl. 3: 1-3) even though some individuals, mainly among the biggest, might be confused with C. paucicostatum Lange. This stratigraphic level is also characterized by individuals belonging to Hecticoceras coelatum species (Pl. 2: 9), whose ribs pass through the venter, Eochetoceras villersensis (M) and E. hersilia (m) (d’ORBIGNY) (Pl. 3: 12).

In the sub-Tethyan Province, this Scarburgense biohorizon is also characterized by Hecticoceras with less pronounced sculpturing such as H. chatillonense (Pl. 3: 7, 11) mainly in 8A (lower part), and H. socini (in Grygi, 1990), mainly in 8B (upper part).

Peltoceratins from level 8B (Pl. 3: 8, 9) display abrupt bifurcation points at or near the umbilical seam (BONNOT et al., 1997). At this level, Taramellicerases is slightly more frequent (Pl. 3: 14a, 14b).

- Level 9 (at Thuoux: 20 m thick).

At Thuoux, this level corresponds to the Scarburgense biohorizon (upper part). Abruptly, ammonites are less frequent and Cardioceras is very scarce. Records of Eochetoceras villersensis (d’ORBIGNY) and E. hersilia (d’ORBIGNY) at the base of that level, as in the French Jura (JARDAT, 2010), and the disappearance of Hecticoceras coelatum COQUAND are typical of that level. From this stratigraphic level, Phylloceratina become more abundant than Ammonitina, due to a well-known deepening in numerous sections in Western Europe (DARDEAU et al., 1994). In other sections, very similar to that investigated at Thuoux, the top of this stratigraphic level has yielded some Cardioceras close to the species C. woodhamense ARKELL (FORTWENGLER & MARCHAND, 1994a; MARCHAND et al., nearing completion). C. woodhamense ARKELL definitively appears above the Scarburgense horizon and not below, as claimed by CALLOMON (1993) and PAGE et al. (2006, 2009a, b).

- Level 10 (at Thuoux: over 100 m thick).

Though ammonites are very rare, faunal assemblages indicate the Woodhamense horizon and the upper part of the basal Praecondatum Subzone.

In conclusion, the correlation potential of ammonites collected from the Thuoux section is extremely precise (Fig. 5).

In this paper, subdivisions proposed for the Thuoux GSSP are the same proposed in 1997 by THIERRY et al. for the Callovian and CARIOT et al. for the Oxfordian. They are known in all Western Europe and have been used without difficulty in the United Kingdom, Germany, Switzerland and Poland (MARCHAND & TARKOWSKI, 1990), and only on the basis of Peltoceratins in Bulgaria and Rumania where Cardioceratins are unknown. Correlations may be also possible:

- with Russia, where authors show that these subdivisions can also be used reliably in the boreal domain,
- with South America (Chile, Argentina), Madagascar and India through use of Peltoceratins (Peltoceratoides) as shown by BONNOT et al. (1977, 2002),
- possibly for the Canadian Oxfordian through Cardioceratinae.  

b. Foraminifera

On certain samples, JUTSON (in POULSEN & JUTSON, 1996) wrote: "Thuoux foraminifers and nannoplankton in the studied interval were low in diversity but moderate in abundance. Preservation was, in general, poor. Only two species recorded were stratigraphically significant". These two species are Ophthalmidium compressum OSTENFELD and O struamosum (GUMBEL); O. compressum disappears at the Thuouxensis biohorizon where it is replaced by O. struamosum, the latter appearing in the Paucicostatum biohorizon and persisting into the Scarburgense biohorizon.

c. Dinoflagellates

This study was carried out by N.E. POULSEN from sampling performed in 1994 during the 4th Oxfordian and Kimmeridgian Working Group Meeting. Results can be summarized as follows. "Most of the stratigraphical important species are present in the assemblages" (citations from POULSEN in POULSEN & JUTSON, 1996). Comparison of the range charts for the Savournon and Thuoux sections shows that important species occur in both sections. Moreover, POULSEN (in POULSEN & JUTSON, 1996) confirms that Durotrigia filapicata GOCHT disappears at the top of the
Callovian whereas *Wanaea fimbriata* SARGEANT appears at the base of the Oxfordian, but is very rare. These results are in accordance with what is known "in North Sea Region and in East Greenland". POULSEN (in POULSEN & JUTSON, 1996) also noted that "the preservation of the palynomorphs in the Thuoux section is poor and the number of cysts is low" and that "the Savournon section dinoflagellate cysts are excellently preserved and present in large numbers".

d. **Ostracodes**

Preliminary research shows they seem to be rare but present at Savournon (TESAKOVA, 2008).

e. **Isotope stratigraphy**

This may be feasible from rare belemnite rostra.

f. **Magnetostratigraphy**

All samples are negatively remagnetized (B. GALBRUN, oral communication).

<table>
<thead>
<tr>
<th>Lamberti Zone</th>
<th>Mariae Zone</th>
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<tr>
<td><strong>Lamberti Subzone</strong></td>
<td><strong>Mariae Subzone</strong></td>
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<tr>
<td>Lamb</td>
<td>Paucicostatum</td>
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<td>5B</td>
<td>6A</td>
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<tr>
<td><em>Kosmoceras duncani</em> (in Badaluta)</td>
<td><em>Bemiceras cf. inconspicuum</em></td>
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<tr>
<td><em>Quenstedtoceras lamberti</em></td>
<td><em>Cardioceras paucicostatum</em></td>
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<tr>
<td><em>Properis, bernensis</em></td>
<td><em>Taramelliceras episcopalis</em></td>
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<td><em>Eochetoceras villoisensis</em></td>
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**Figure 5:** Vertical range of the major species of ammonites found in the "Terres Noires" Formation at the Callovian-Oxfordian boundary (*NB*: 5B to 10A are field subdivisions).
4. Satisfaction of geological requirements for Thuoux GSSP proposal

The Thuoux section fulfills numerous requirements proposed in the Guidelines of the ICS, i.e., International Commission on Stratigraphy (Remane et al., 1996).

a. Geological requirements

- Exposure over an adequate thickness (Fig. 2).
- Biohorizons: Lamberti (5B), Paucicostatum (6A and 6B), Thuouxensis (7A and 7B) and Scarburgense (8A and 8B) reach 60m in thickness. Vegetation is very sparse and exposed levels are easy to recognize.
- Continuous sedimentation (Fig. 3): the faunal succession, together with the thickness of sedimentary rock, indicates very continuous sedimentation.
- The rate of sedimentation: for the investigated stratigraphic interval in Western Europe, such a substantial thickness is known only in the "Terres Noires" area of the South-Eastern Basin (together with the centre of the Paris Basin).
- NB: On the basis of biostratigraphic data, the sedimentation rate is 6 to 20 times higher than in Weymouth, UK.
- Absence of synsedimentary and tectonic disturbances: the Thuoux section is undisturbed, and neither faults nor landslides have been noticed. Moreover, strong layer dip makes mixing of faunas unlikely.
- Absence of metamorphism and strong diagenetic alteration: both phenomena are absent. Superficial erosion and weathering maintains the section in a very good state, which makes collection of samples easy for every type of geological study.

b. Biostratigraphic requirements

- Abundance and diversity of well-preserved fossils: ammonites are abundant and well-preserved, and always greatly exceed other macroinvertebrates in abundance. They are often extracted, entire rather than crushed, from calcareous nodules. Fossils at Thuoux are characterised by a mineralogy that is stable in a weathering environment. Though Meléndez (2003, 2004, 2006) asserted the occurrence of pyritic replacement of ammonites at Thuoux, any pyritic ammonites would have been altered to goethite. In fact, neither pyritic nor goethitic preservation is present! Boreal as well as Mesogean faunas can be collected. Moreover, the analysis of ammonite faunas in the South-Eastern Basin in the context of synsedimentary tectonics (Dardeau et al., 1994) has allowed better understanding of faunal distribution in relation to palaeodepth in Western Europe (Marchand & Dardeau, 1979; Marchand, 1984; Marchand et al., 1990). Microfossils are quite numerous and some groups can be used for some biostratigraphic schemes whose precision is, at its best, of subzonal scale.
- Absence of vertical facies changes (Fig. 2): the Callovian / Oxfordian boundary occurs in a series of marls that lack facies changes other than some fluctuations in the carbonate content.
- Favourable facies for long-range biostratigraphic correlation (Fig. 3): the Thuoux section yields three ammonite subfamilies (Cardioceratinae, Peltoceratinae and Hecticoceratinae) whose morphological evolution was rapid, though not synchronous. These factors ensure 1) the reliability of the faunal successions at the Callovian / Oxfordian boundary and 2) the biostratigraphic precision of biostratigraphic units. These three subfamilies also allow correlations not only with all Western Europe but also with the Boreal Realm (North America) and the Pacific Realm (Argentina, Chile). As taxa of these three subfamilies are not always found together, it is important to be able to use three parallel schemes for biostratigraphic control.

c. Other methods

- Radiisotopic dating: not applied.
- Magnetostratigraphy: numerous analyses were always negative in the South-Eastern Basin, in contrast to Redcliff Point.

d. Faunal populations

- Ammonites: at each stratigraphic level examined, ammonites were collected in situ and exhaustively. Thus faunal diagrams depict the faunal composition of each level (each biohorizon commonly being subdivided into two ammonitic sections: lower / upper). They also summarize our knowledge of the palaeodepth of the fossiliferous deposits studied. One of us has even used these faunal diagrams to establish the occurrence of extensional tectonic events during the earliest Oxfordian (Scarburgense Subzone: Marchand, 1986) and more precisely between the Scarburgense and Woodhamense biohorizons (Marchand, 1986) (Fig. 5).
- Foraminifera: diversity is low, but the occurrence of Ophthalmidium compressum Ostenfeld in the uppermost Callovian and Ophthalmidium strumosum (Gumbel) in the lowermost Oxfordian can be used for bio-
stratigraphy.

- Dinoflagellates: *Durotrigia filapicata* Gocht is rare in the uppermost Callovian (Lamberti horizon) and disappears in the lowermost Oxfordian (Scarburgense horizon) where *Wanaea fimbriata* Sargeant, also rare, first occurs.

### e. Other requirements

- Permanently fixed marker: conservation of the section proposed as GSSP is assured at Thuoux. The Thuoux section is located in a huge area of badlands that are not secure for building.

- Accessibility (Fig. 1): access will be free for every researcher. Access is possible from a parking zone (at the nearby cemetery) located 10 minutes' walk from the section, on a gentle slope (30 m difference in height). Researchers will be able to work without constraint by choosing the same biostratigraphic subdivisions proposed by ammonite specialists (D.F. and D.M.). Permanent marking of the biostratigraphic units recorded by the authors is easy to make.

### 5. Correlations and comparisons with the alternative candidate GSSPs

#### a. Redcliff Point, Weymouth, Dorset (UK)

This section, well analysed by Page et al. (2006, 2009a), has six shortcomings, here addressed in order of decreasing importance.

* The first disadvantage is clearly acknowledged by the British authors themselves: the section is not reliably exposed. "For some time, the exposure (Redcliff Point) has been covered by talus and vegetation, but recent coastal erosion has now re-exposed a Callovian-Oxfordian boundary sequence" (in Page, 1994a, b). "The extent and quality of the exposure at Ham Cliff varies from season to season and from year to year, depending on the height of the shingle storm beach and cliff erosion" (in Meléndez, 2003: 30, p. 17). "The section has now re-exposed a Callovian-Oxfordian boundary sequence" (in Page, 1994a, b). "The section has been obscured by slumping in recent years" (in Meléndez: 2003). "The reason why it had been neglected since Arkell's days was that it was usually obscured by slumping and shingle. I remember looking at it in 1956 and actually finding the Lamberti Zone there, in a small outcrop above the shingle. But all I learned was that it confirmed Arkell's report of an occurrence which had been ignored previously. Exceptional storm conditions in the winter of 1991-1992 swept it all clear, giving a fine exposure." And Callonom (in Callonom & Coope, 1993) described an exceptionally clean section at Redcliff Point where *C. woodhamense* Arkell occurs below *C. scarburgense* (Young & Bird). Unfortunately, Page et al. (2009a) have accepted that mistaken succession.

* The second drawback is palaeontological: the faunal assemblage is poorly preserved, with rather low diversity. The assemblage has not been illustrated, except for the Cardioceratins (1 plate). It should be emphasized that Cardioceratins predominate at Redcliff Point, but are "typically crushed" (though not always the inner whorls). This makes observation of the venter very difficult so that no fully reliable determination is possible. In addition, Hecticoceratinae are rare and the absence (in Page et al., 2009a) of Hecticoceras (Brightia) *thuouxensis* Fortwenger & Marchand does not allow recognition of the Thuouxensis biohorizon. However, this species is present close to Redcliff Point: it has been figured by Chapman (1999: Pl. 7, fig. F) in association with *H. (B.) chatillonense* de Loriol (Chapman, 1999: Pl. 7, figs. G-H). *H. (B.) thuouxensis* was also collected in Paris Basin boreholes (Thierry et al., 2006) and in the Jura (Jardat, 2010). It is not a rare species at that level. Finally, individuals belonging to the genus Peltocestroidea, which is present though not abundant, were not used by Page and collaborators as biostratigraphic markers even though they are chronologically as precise as Cardioceras at the Callovian / Oxfordian boundary in the South-Eastern Basin of France (Fortwenger et al., 1997; Bonnot et al., 1997, 2002).

* The third disadvantage concerns ammonite systematics. The Page et al. (2009a, b) proposal relies on a dubious determination of Cardioceratinae species as well as an erroneous phylogeny.

- *Cardioceras paucicostatum* Lange is close to *C. scarburgense* (Young & Bird) and must be included in the genus Cardioceras. Why is this? The first representatives of *C. scarburgense* (Young & Bird) are in morphological continuity with *paucicostatum* Lange, which is confirmed by the existence of "tea-
tures transitional to \textit{C. (Pavloviceras) scarburgense} (\textsc{Young \\& Bird}). Both forms are present in horizons LL3c-d and Ox1 of \textsc{Page et al.} (2009a, p. 93) at Redcliff Point;

- \textit{Cardioceras redcliffense} \textsc{Page et al.} (2006), named \textit{Cardioceras (Pavloviceras) redclifffense} (2009a), in our opinion has no palaeontological reality. We regard \textit{C. redcliffense} \textsc{Page et al.} as a synonym of \textit{Cardioceras paucicostatum} \textsc{Lange}, 1973. As a matter of fact, in the Ox1 biohorizon, the holotype of \textit{C. redcliffense} (\textsc{Page et al.}, 2009a: pl. 1 D) shows a \textit{C. scarburgense}-like morphology but among a population where "paucicostatum" morphology is still abundant (\textsc{Page et al.}, 2009a: Pl. 1 C, E-G). Unfortunately, no information on Hecticoceratins and Peltoceratins is available to permit precise correlation with the Thuoux section.

- \textit{Cardioceras scarburgense} (\textsc{Young \\& Bird}) from Scarburgense biohorizon is quite easy to differentiate from \textit{C. paucicostatum} \textsc{Lange}. The holotype of \textit{C. scarburgense}, from Scarborough, was figured by \textsc{Arkell} (1939: Pl. X, fig. 1a-c). It is characterized by a) a moderate number of primary ribs, b) secondary ribs that are more or less prospiriradiate and c) a venter lacking crenulation in lateral view. These morphological characteristics are exactly the same:
  o at Authoison (Département de Hau-te-Saône, France), where a large population of \textit{C. scarburgense} shows exactly the morphological variations of that species, well illustrated by \textsc{Maire} in 1938 (Scarburgense biohorizon);
  o in populations of \textit{C. scarburgense} collected in the levels 8A/8B and basal 9 from "Terres Noires" of French South-Eastern Basin (\textsc{Fortwengler \\& Marchand}, 1994a);
  o in populations of \textit{C. scarburgense} collected at Uzelot (in Boulonnais) from the levels IT 20/30 and IT 30/40 (\textsc{Vidier et al.}, 1993);
  o in the horizons named Scarbu (1) and Scarbu (2) from French Jura (\textsc{Jardat}, 2010).

- \textit{Cardioceras woodhamense} \textsc{Arkell} is for us clearly younger than \textit{C. scarburgense} (\textsc{Young \\& Bird}).

Remark: \textsc{Page et al.} (2009a: p. 92 and 95) placed the Redcliffense biohorizon just below the Woodhamense biohorizon (Ox2) and accepted the Scarburgense biohorizon (Ox3) above the Woodhamense biohorizon. Quite evidently, that stratigraphy cannot be right.

In a forthcoming paper (\textsc{Marchand et al.}, nearing completion) we confirm through very close analysis of facts determined from numerous sections that \textit{C. woodhamense} \textsc{Arkell} is younger than \textit{C. scarburgense} (\textsc{Young \\& Bird}) and that ammonite populations from the Scarburgense and Woodhamense horizons are clearly very different from each other. Some insights from our results:

(i) About \textit{scarburgense} (\textsc{Young \\& Bird}) and \textit{woodhamense} \textsc{Arkell} (\textsc{Fortwengler \\& Marchand}, 1994b; \textsc{Marchand et al.}, nearing completion).

1. \textit{C. scarburgense} (\textsc{Young \\& Bird}) does not yet have an individualized keel, and shows no proverse ribs making a chevron (V-shape) on the venter;

2. In contrast, the species \textit{C. woodhamense}, erected by \textsc{Arkell} in 1939, incorporates an apomorphy that characterizes every later \textit{Cardioceras} species: the presence of a keel or, more precisely, of primary and secondary ribs elevated on the ventral axis, forming a fairly prominent chevron. In lateral view, \textit{C. woodhamense} shows a rather crenulated venter, which never occurs in \textit{C. scarburgense}.

(ii) About Woodham Brick Pit Cardioceratinae and about \textit{C. redclifffense} (\textsc{Marchand et al.}, nearing completion).

1. Cardioceratinae from the Woodham Brick Pit, pictured by \textsc{Arkell} under the following names: \textit{Q. mariae}, \textit{Q. omphaloids}, \textit{Q. aff. williamsoni} (all with undulating ribs in inner whorls like the holotype of \textit{C. woodhamense} \textsc{Arkell}), correspond to the "thick" and "medium thick" morphotypes of \textit{C. woodhamense} \textsc{Arkell}.

2. As consequence: the 157 \textit{C. scarburgense} not pictured by \textsc{Arkell} are simply, from a biological point of view, the "thin morph" of \textit{C. woodhamense} \textsc{Arkell}.

So our conclusion is that, at Woodham Brick Pit, there is a lacuna in place of the Scarburgense biohorizon because the Woodhamense biohorizon (levels A and B of \textsc{Arkell}, 1939) lies directly on the Upper Callovian (stratigraphic level C, \textit{Lamberti} biohorizon, \textsc{Arkell}, 1939).

Remark: The same lacuna at the Scarburgense biohorizon is also known in Normandy (\textsc{Raynaud}, oral
concerns the thickness of the section.

The fifth drawback concerns the thickness of the section. The small thickness observed at Redcliff Point makes any cyclostratigraphic analysis dubious. By contrast, such an analysis may be made in twenty sections of the South-Eastern Basin where precise biostratigraphic control is available. The Thuoux and Saint-Pierre-d’Argençon sections, for instance, could be sampled every 8 cm.

* The sixth drawback concerns correlations with the Boreal Domain and the Pacific Province.

In the Redcliff Point GSSP proposal (p. 90 - 91), Page et al. (2009a) have written about the "bioprovincial context" in general, without any attempt to correlate the various biostratigraphic schemes with each other.

- For the Arctic Province, they write only that "there is no reason to suspect that the basic succession of Quenstedtoceras to Cardioceras faunas differs in any significant way from that in adjacent Subboreal areas". But they also claim that "there is some evidence of endemic cardioceratid in ... North America".

- For the Subboreal Province, they refer only to the domination of the Cardioceratids. On the Isle of Skye (Scotland), only Cardioceratids occur, except for one level which yields only Peltoceratoides sp. (Turner, 1966). That stratigraphic level - very easy to find at Staffin Bay - marks the topmost Praeocordatum Subzone, just a little below the Bukowskii Subzone (Marchand & Dardeau, 1979).

* No confident conclusions can be drawn from the Russian forms, which are very well described by Kiselev et al. (2004, 2005, 2006), nor from the South American and Pacific provinces.

For us, this is problematic because every GSSP must be, by definition, a reference point for any available biostratigraphic schemes. That is the true aim of a GSSP.

* Appendix: The case of Peyrale (Savournon, near Serres, Hautes-Alpes) proposed as GSSP auxiliary section.

Since 2003, Meléndez has considered that the Peyrale section located close to Savournon “displays some particular features making it a suitable candidate section for Oxfordian GSSP". In 2007, in a new paper by Meléndez, Atrops and Page (2007: fig. 3), these authors proposed this section as an "auxiliary section" of the Redcliff Point GSSP. The first 10 m are attributed to the "Lamberti biozone" (levels 10 to 21) and the last 4-5 m (levels 19-21) yielded C. paucicostatum Lange (= Q. paucicostatum in Page et al., 2009a). As in the Redcliff section, Meléndez,
ATROPS and PAGE recognized three levels in the Paucicostatum horizon, which are from lower to upper:

- **C. paucicostatum-alpha** "involute forms showing thick, bundled ribbing with low point of furcation";
- **C. paucicostatum-beta** "more typical, thickly ribbed (non-bundled) evolute forms";
- **C. paucicostatum-gamma**, "showing finer, slightly projected ribbing and the beginning of a ventral keel on innermost whorl"; these gamma forms are "common at level 21-c and become rare at bed 23a."

These authors place the "base of the Oxfordian stage at the base of the level 23 coinciding with the first recording of some specimens of Cardioceras of the group C. redcliffense PAGE et al., a new form displaying clear intermediate features between C. paucicostatum-gamma and C. scarburgense (YOUNG & BIRD)".

At this juncture, two points should be made. In our study of the Peyrale/Savournon section (FORTWENGLER & MARCHAND, 1994d) we were able to state that:

- we could not identify three sub-biohorizons within our Paucicostatum biohorizon,
- we did not see "the development of a clear ventral keel in the inner whorls up to 15-20 mm of shell diameter and the ribbing on the flank becoming slightly finer and more flexuous" before the first occurrence of C. scarburgense.

Final remark: the Woodhamense biohorizon, which at Redcliff Point (PAGE et al., 2009a) lies between the Redcliffense and Scarburgense biohorizons, vanishes in the Peyrale section. Since we know the Peyrale/ Savournon section very well (FORTWENGLER & MARCHAND, 1994b), we are aware that the Woodhamense biohorizon is present at Savournon. However we collected that species more than 25 m above the Paucicostatum horizon. As everywhere else, the Woodhamense biohorizon lies above the Scarburgense horizon, and not below.

**b. Dubki section: Russia**

Interesting information on the Callovian / Oxfordian boundary comes from our Russian colleagues and a short summary follows. According to KISELEV and ROGOV (2004, 2005) and KISELEV et al. (2006), the Callovian / Oxfordian boundary is readily identifiable at Dubki, Saratov (52°N parallel). Thus, in 2006, they proposed the Dubki section as a candidate GSSP for the Lower Oxfordian boundary. We wish to address certain points related to this proposal. The Lamberti Zone (Upper Callovian), 4.60m thick, is subdivided into 2 subzones (Henrici and Lamberti) and 5 biohorizons (Henrici, Praelamberti, Lamberti, Majorowski and Paucicostatum).

The Mariea Zone, 2.60m thick, is subdivided into two subzones (Scarburgense, Præcordatum) and 3 biohorizons (Scarburgense, Alphacordatum and Praecordatum). In Russia, the genus Tarameliceras and the species Creniceras rengeri occur quite late (Bukowski Subzone). Latest Kosmoceras disappears at the top of the Majorowski biohorizon (with the species K. majorowski), whereas the last occurrence of the genus Quenstedtoceras is registered slightly higher, at the Callovian / Oxfordian boundary, consistent with Western Europe.

Concerning ostracods, the species Infacythere dulcis disappears at the Callovian / Oxfordian boundary whereas Nophreycthyere oxfordiana first occurs slightly above that boundary (TESAKOVA, 2008). The same level is readily recognized from foraminifera which are represented by diverse and abundant benthic taxa. The Callovian / Oxfordian boundary coincides with the boundary between the Lenticulina tunida and Epistomina elschankensis zones and the Ophthalmidium sagittatum and Epistomina vergens zones. This section has yielded good palaeomagnetic results based on reversals, except at the Callovian / Oxfordian boundary.

In 2004, KISELEV and ROGOV had proposed an identical zonation for the Lamberti Subzone. In contrast, their proposed subdivision of the Mariea Zone differs slightly from our proposal.

At the base is the Scarburgense biohorizon from which they record two species, Vertumniceras luppovi (AMANNJASOV) and Sublunoceras deperditum (ROLLIER), that are absent from assemblages in France, the United Kingdom and Switzerland. However, they have accepted the Woodhamense biohorizon as proposed by FORTWENGLER and MARCHAND in 1994b. This is reasonable as we regard the individual of Pl. 2: 17 of the former authors (Orenbourg area: in KISELEV & ROGOV, 2004) as being very close to C. woodhamense var. normandiana. KISELEV and ROGOV (2004) consider that the Praecordatum Subzone begins with an unnamed horizon that yields Cardioceras praecordatum and Peltoceras sp., overlain by the Renggeri horizon that yields Tarameliceras (Richeiceras), Creniceras, Peltoceras sp. and Cardioceras cf. alphacordatum. Their pictures of Q. henrici, Q. praelamberti, Q. lamberti, C. scarburgense, C. præmartini, C. alphacordatum, C. praecordatum and C. bukowski seem to us to be correctly identified except for C. costicardia (their fig. 11/12), C. cordatum (their fig. 13/14) and C. paucicostatum (their fig. 15/16). Species found in France and the United Kingdom have been shown to be present in Russia also, which makes correlation possible, as KNIAZEV (1975) had already demonstrated.

The importance of the Dubki section is thus well established, in particular, due to mixing of "Boreal" and "Tethyan" faunas, which make
long-distance correlations possible. Noticeable is that this faunal mixing, as frequently in Western Europe, occurs near the boundary between the Scarburgense and Praecordatum biohorizons whenever the palaeoenvironment was sufficiently open.

- Nevertheless, the stratigraphic ranges of some species are not in strict accordance with what we know in the "Terres Noires" and at Thuoux in particular. For example the Paucicotostatum biohorizon at Dubki yields both Poculisphinctes and Alligaticeras (Gulyaev et al., 2002), and Euaspidoceras subbabeaunum (Sintzow) sensu Jeannet even crosses the Callovian / Oxfordian boundary;
- Hectoceratinae appears quite rare in that area and absent above the lowermost Oxfordian levels. Thus, general correlation with the Thuoux section is not yet demonstrated with that subfamily;
- Although the faunal record shows considerable similarity with the Tethyan regions, there is no quantitative study yet.

It is important to note that some species recorded at Dubki have been identified from other deposits by Rogov and Egorov (2003) and Kiselev and Rogov (2005). We are in agreement with almost all the proposed names. Accurate correlation with Western Europe is now possible with the help of these excellent papers.

c. Our proposals for correlation outside of Europe

* Argentina (biochronological interpretation: A. Bonnot)

In "Biostratigraphy of the transect Chacay Melehue-Sierra de Reyes, Argentina", PARENT (1998) considered the dimorph pair Peltoceras gr. constantii (M) / arduennense (m) typical of the Cordatum Zone (lower part). The proposed occurrence of Prososphinctes gr. mazuricus / claramontanus and Prososphinctes gr. mairei / matheyi confirms that interpretation. By contrast Mirospinhinctes gr. syriacus / regularis and Euaspidoceras cf. kobyi would rather suggest the Mariae Zone, and some individuals collected at Rahueco are similar to those described from Mount Hermon (Syria) for the lowermost Oxfordian. In our opinion, many specimens from Syria are very close to Eochetoceras villersensis / hersilia, a dimorph species that characterizes the top of the Lamberti Subzone up to the base of the Woodhamense biohorizon (Raynaud et al., nearing completion) in France and the United Kingdom.

Later, in 2006, PARENT compared ammonite successions of the Middle Callovian to Upper Oxfordian in both Neuquén-Mendoza and Tarapaca basins. Near to the Callovian-Oxfordian boundary he recognized:
- Athleta Zone, demonstrated by the occurrence of Pseudopeltoceras sp. and Peltoceras (P.) cf. athleta;
- Primus Zone that yields the genus Distichoceras (top of Athleta Zone / probable Lamberti Zone);
- In the Neuquén-Mendoza Basin, the lower Oxfordian is represented by the Pressulus Zone only, which yields 3 species of genus Peltoceratoïdes, P. pressulus, P. balleuensis and P. cf. intercissus. By comparison with Western European species, these species indicate the Scarburgense Subzone (BONNOT et al., 2002). However, if the identifications of Perispinhinctes cf. mazuricus / matheyi are correct, this instead suggests the base of the Praecordatum Subzone;
- In the Tarapacá Basin, the lower Oxfordian is represented by 3 zones; it begins with Peltoceratoïdes retrocostatum and P. dimorphous (Dimorphous Zone) and then continues with Peltoceratoïdes eugenii and P. balleuensis (Eugenii Zone).

* Chile (biochronological interpretation: A. Bonnot).

Hillebrandt and Groshcke (1995) have described a biostratigraphic succession based on different species of the genus Peltoceratoïdes. They considered the Primus Zone to be equivalent to the Lamberti Zone, and Dimorphus and Eugenii zones equivalent to the Mariae and Cordatum zones.

As has been pointed out by BONNOT et al. (2002), "if we roll out the hypothesis of pronounced endemism ... the Chilean forms described ... can all be ascribed either to Peltoceratoïdes eugenii (d'Orbigny) or to Peltoceratoïdes athletoides (Lahusen)". As a consequence: their "Eugenii Zone" must be correlated with the Athletoïdes Subzone of the Mediterranean province = Scarburgense Subzone of Western Europe.

* North America (biochronological proposition: D. Marchand & D. Fortwengler).

Reeside (1919) figured ammonites from Wyoming (Sundance Formation) and from Montana (Ellis Formation). In these regions, he recognized the genus Quenstedtoceras and 5 species. In our opinion, only Q. collieri (from the Ellis Formation) can be a true Quenstedtoceras. The other species (of the Sundance Formation) seem to have a small keel and are, probably, true Cardioceras. Reeside (1919) distinguished three groups of cardioceratids, for us, from the Mariae Zone:

1. Cardioceras albanense, C. crassum, C. la-tum, and C. russelli, Quenstedtoceras ho-veyi, Q. subhumidum and Q. suspectum. These "species" have morphological affinities with European fauna of the Scarburgens-e Subzone;
2. *Cardioceras americanum*, *C. aurorae*, *C. bellevourchense*, *C. crokense*, *C. plattense*, *C. obtusum* and *C. wyomingense*. These "species" have morphological affinities with the European fauna from the base of the Praecordatum Subzone;

3. *Cardioceras alaskense* (but not Pl. 7, figs. 1-3), *C. cordiforme*, *C. distans*, *C. haresi*, *C. hyatti*, *C. liloetense*, *C. martini*, *C. schuberti*, *C. spiniferum*, *C. stantoni* and *C. whitfieldi* have morphological affinities with the European fauna from the upper part of the Praecordatum Subzone.

* "Pacific area part" (BONNOT et al., 2002)

**Peltoceratoides williamsoni** (PHILLIPS) and allied species are found almost worldwide, and correlations can be envisaged between Western Europe and the Indo-Madagascar domain + Indonesia + Japan, where the genus *Peltoceratoides* is known.

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