Uppermost Albian biostratigraphy and chronostratigraphy

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Abstract: The Albian Stage is the highest chronostratigraphic unit of the Lower Cretaceous Series and underlies the Cenomanian Stage of the Upper Cretaceous Series. The Albian is divided into three substages, each of which is composed of two or three zones based on distinctive and phylogenetically related ammonite assemblages. The uppermost zone of the Upper Albian Substage, the *Stoliczkaia dispar* Zone, is found in many Western European condensed sections. The ammonite assemblage in the thin glauconitic sandstone near La Vraconne, Switzerland, was defined as the 'Vraconnian Stage' in 1868. However this concept has been little used and was abandoned in 1963 as part of the Cretaceous chronostratigraphic scale. A recent proposal to resurrect and redefine this stage is based on a number of criteria and very detailed and reliable stratigraphic data. A quantitative biostratigraphic analysis of the ammonite ranges in the key sections shows that the proposed subzones of the *S. dispar* Zone have discordant ranges. Furthermore, the utility of a 'Vraconnian Stage' between the Albian and Cenomanian stages is geographically limited and the concept embraces one of many depositional sequence cycles of the Albian. The reinstatement of a 'Vraconnian Stage' is not recommended.

Key Words: Albian; Vraconnian; ammonites; planktic foraminifers; graphic correlation; age calibration.

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Résumé : ***Biostratigraphie et chronostratigraphie de l'Albien sommital/terminal.-*** L'étage Albien constitue l'unité chronostratigraphique la plus élevée du Crétacé inférieur et repose sous l'étage Cénomanien du Crétacé supérieur. L'Albien est divisé en trois sous-étages, chacun comprenant deux ou trois zones établies sur des associations d'ammonites distinctes mais phylogénétiquement reliées. La zone sommitale du sous-étage Albien supérieur, la Zone à *Stoliczkaia dispar*, a été identifiée au sein de nombreuses séries condensées en Europe occidentale. L'association d'ammonite reconnue dans le mince niveau de grès glauconieux des environs de La Vraconne (Suisse) a été définie comme 'étage Vraconnien' en 1868. Toutefois ce concept a été peu usité et fut abandonné en 1963 en tant qu'unité de l'échelle chronostratigraphique du Crétacé. Il a été récemment proposé de réhabiliter et de redéfinir cet étage sur la base d'un certain nombre de critères et de données stratigraphiques très détaillées et fiables. Or une analyse biostratigraphique quantitative des répartitions des ammonites dans les coupes clefs révèle que les sous-zones proposées pour la subdivision de la Zone à *S. dispar* correspondent à des intervalles non concordants. En outre l'intérêt de placer un 'étage Vraconnien' entre les étages Albien et Cénomanien apparaît géographiquement limité, et le concept correspond à une seule des nombreuses séquences de dépôt de l'Albien. Il n'est donc pas recommandé de restaurer un 'étage Vraconnien'.

Mots-Clefs : Albien ; Vraconnien ; ammonites ; foraminifères planctoniques ; correlation graphique ; calibration des âges.

Introduction

Recently Amédro (2002, 2008), Amédro & Robaszynski (2008) and Robaszynski *et alii* (2007) proposed to reinstate the 'Vraconnian Stage' between the Albian and Cenomanian stages. This proposition, which would significantly modify the Cretaceous geologic column, merits careful and thorough analysis. Our objectives are to provide a testable global biostratigraphic database with which to evaluate the ranges of key uppermost Albian species and to calibrate their ranges to a numerical time scale.

The Cretaceous System is composed of twelve stages that can be correlated world-wide and are of different durations (Hancock, 2003). The Albian Stage is the youngest chronostratigraphic unit of the Lower Cretaceous Series and one of the longest Cretaceous stages, about 13 to 15 myr. The Albian Stage was defined by d'Orbigny (1840-1842) to include the fossil assemblages in shale and

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glauconite sands cropping out along the Aube River in the Department of Aube on the eastern margin of the Paris Basin (MAGNIEZ-JANNIN & RAT, 1980). A stratotype section along the Aube River was composited from outcrop sections and nearby boreholes (LARCHER *et alii*, 1965; AMÉDRO, 1992). The Albian biota in the Paris Basin is transitional between Boreal and Tethyan realms. The concepts of Albian ammonite zones have evolved over a period of time beginning in 1868 when the "*Ammonites mammillaris*" zone (de RANCE, 1868) (now the *Douvilleiceras mammillatum* Zone) and the "zone of *Ammonites inflatus*" (de LAPPARENT, 1868) (now considered equivalent to the *Stoliczkaia dispar* Zone) were proposed (RAWSON *et alii*, 1978). The current zonal scheme (Fig. 1) was composed by SPATH (1923) and BREISTROFFER (1947) and modified by OWEN (1971) and AMÉDRO (1992). The zonal succession has been relatively stable since 1947 and most are interval zones defined by the first appearance of an ammonite species (FO; AMÉDRO, 1992).

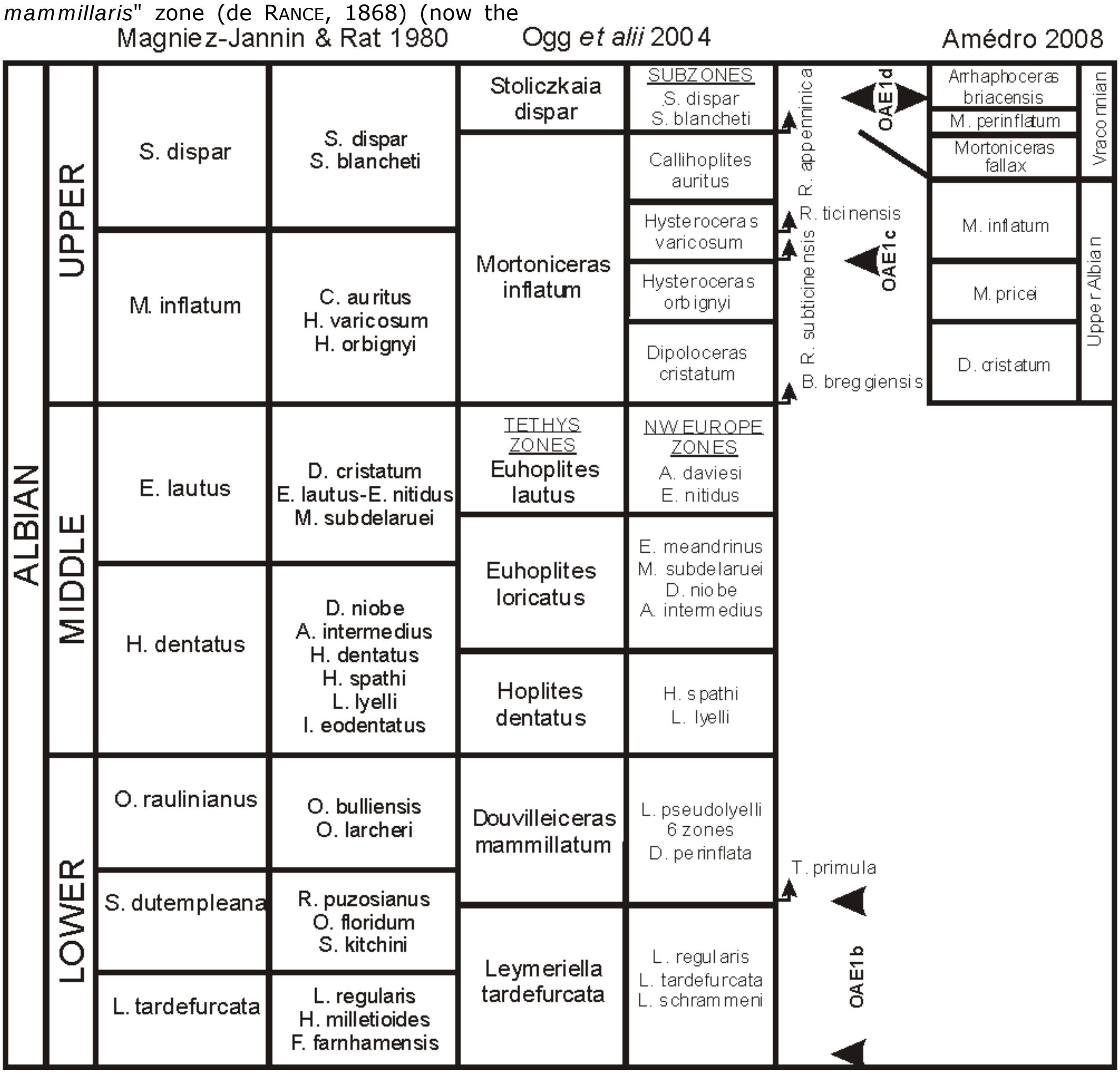

Figure 1: Chart comparing three stage and substage concepts of the Albian (P. DESTOMBES, 1979 in MAGNIEZ-JANNIN & RAT, 1980; OGG *et alii*, 2004, and AMÉDRO, 2008). The positions of Albian anoxic events and key microfossils were interpolated by OGG *et alii* (2004).

The Albian Stage is divided into three substages, Lower, Middle and Upper. Although stratotype sections for these substages are yet to be agreed upon, here they are used formally following HART *et alii* (1996) and are capitalized. The zonal boundaries of the substages have been used consistently since 1947 (Fig. 1). Prior to 1947, however, two different criteria were used to define the base of the Upper Albian Substage. SPATH (1923, 1941) placed the boundary at the top of the *Dipoloceras cristatum* Subzone, which directly overlies the *Euhoplites lautus* Zone (OWEN, 1971). Alternatively BREISTROFFER (1947) placed the Cristatum Subzone in the basal Upper Albian *Mortoniceras inflatum* Zone. This later opinion has been followed since (BIRKELUND *et alii*, 1984; OWEN, 1984a, 1984b; HANCOCK, 1991; HART *et alii*,

1996; RAWSON & HOEDEMAEKER, 1999; HOEDEMAEKER & RAWSON, 2000; HOEDEMAEKER *et alii*, 2003). The rationale for this change is reviewed by OWEN (1971) and HART *et alii* (1996). In North America a regional transgressive unconformity coincides with the top boundary of the Cristatum Subzone, which is a widespread mappable contact (SCOTT *et alii*, 2003).

The Albian Stage comprises the evolutionary origins and/or diversification of seven families of ammonites. Zones of the Lower, Middle and Upper Albian substages are based mainly on species of the families of Lyelliceratidae, Hoplitidae, and Brancoceratidae. Four heteromorph families first appear in the Albian, Anisoceratidae, Baculitidae, Hamitidae, and Turrilitidae, but are not used to define zones until their appearance in the Upper Cretaceous.

The 'Vraconnian Stage' was proposed by RENEVIER (1868) for a 2 m-thick condensed interval of green glauconitic sand with a distinctive ammonite fauna between the Upper Albian and Lower Cenomanian substages near La Vraconne in western Switzerland. The ammonite assemblage is part of the *Stoliczkaia dispar* Zone and the lithostratigraphic unit correlates with the Upper Gault and Upper Greensand in England (Fig. 1). This stage was discarded in 1963 (COLLIGNON, 1965; RAWSON *et alii*, 1978; HANCOCK, 1991, 2003, among many others). However the 'Vraconnian Stage' has been resurrected and redefined by AMÉDRO (2002, 2008), AMÉDRO & ROBASZYNSKI (2008) and by ROBASZYNSKI *et alii* (2007). AMÉDRO cites five reasons for recognizing 'Vraconnian' sedimentary strata as a stage between the Albian and Cenomanian stages: (1) the interval is mappable in Western Europe, (2) the interval is a third-order depositional cycle that records an important eustatic event, (3) the interval has a distinctive and diverse fossil assemblage that can be recognized outside Europe, (4) its 2 to 3 myr duration is equivalent to that of the Santonian Stage, and (5) in the Vocontian Basin the interval is more than 100 m thick, which is thicker than the underlying part of the Albian (AMÉDRO, 2002, 2008). AMÉDRO has presented detailed lithostratigraphic and biostratigraphic data of twelve sections in Europe, Tunisia, Madagascar, and California to support his proposal. For the first time he presents a regional lithostratigraphic correlation of many of these sections. HANCOCK (2003) reviewed the history of the rejection of the 'Vraconnian' concept by the community of Lower Cretaceous stratigraphers beginning in 1963 and believed that reasons to revive 'Vraconnian' were "trivial". He noted that most 'Vraconnian' sections are condensed intervals.

As a framework for discussing the wisdom of revising the Albian Stage by reinstating the 'Vraconnian Stage', a review of the stage concept is relevant. "A stage is a chronostratigraphic unit of smaller scope and rank than a series. It is most commonly of greatest use in intra-continental classification and correlation, although it has the potential for worldwide recognition" (NACSN, 2005, p. 1582). As a chronostratigraphic unit the Albian Stage has synchronous boundaries and is the physical evidence or 'material referent' of a time interval, the Albian Age. The Albian Stage has traditionally been defined by a set of ammonite biozones (Fig. 1): d'ORBIGNY, 1840-1842; SPATH, 1923; P. & J.-P. DESTOMBES, 1965; OWEN, 1984a, 1984b; HANCOCK, 1991; HART *et alii*, 1996, among others. The Global Stratotype Section and Point (GSSP) have yet to be selected to define the basal boundary although an excellent section has been proposed (KENNEDY *et alii*, 2002). The upper boundary of the Albian Stage is defined by the base Cenomanian Stage GSSP at Mont Risou, France (GALE *et alii*, 1996; KENNEDY *et alii*, 2004).

Methodology of integrating biostratigraphic data

The integrated ranges of select ammonites in seven key sections defined three zones of the Vraconnian (AMÉDRO, 2008, Fig. 4 ; Fig. 1, Table 1). The ranges of key planktic foraminifera in the Tunisian sections and the French Mont Risou section were added to that set of species by ROBASZYNSKI *et alii* (2007). However most of the ammonite species are found in only one or two sections (AMÉDRO, 2008). To test the accuracy of the integration of species ranges the quantitative technique of graphic correlation is used in this report. Graphic correlation (GC) provides an objective method to compare the ranges of species in multiple sections and the outcome can be tested independently.

Graphic correlation (GC) is a quantitative, non-statistical, technique that determines the coeval relationships between two sections by comparing the ranges of event records in both sections (CARNEY & PIERCE, 1995). A graph of any pair of sections is an X/Y plot of the FOs (first appearances) and LOs (last appearances) of taxa found in both sections. The interpreter places a line of correlation (LOC) through the tops and bases that are at their maximum range in both sections. This LOC is the most constrained hypothesis of synchroneity between the two sections and extends the fewest bioevents. The LOC also accounts for hiatuses or faults at stratal discontinuities indicated by the lithostratigraphic record. The position of the LOC is defined by the equation for a regression line. Explanation and examples of the graphic technique are illustrated by MILLER (1977) and CARNEY & PIERCE (1995). By iteratively graphing successive sections a database of species ranges is compiled. The accuracy of these ranges depends on the number of sections, preservation and correct identification of the species. Such a database is testable and the process is transparent so that the fossil occurrence in each section can be evaluated to determine its accuracy. This process compiles data of many specialists who have studied numerous global sections.

Mont Risou, France, Section	FO meters	LO meters
Base limestone interval	330 m	
Actinoceramus sulcatus	50	78
Actinoceramus subsulcatus	25	
Anisoceras salei	78	
Anisoceras perarmatum	78	
Arrhaphoceras briacensis	305	
Dipoloceras cristatum	18	25
Hysteroceras orbignyi (as sp.)	78	
Lechites moreti	155	
Mantelliceras mantelli		205
Mariella gresslyi	155	
Mortoniceras perinflatum		205
Rota globotruncanoides	295	
Turrilitoides hugardianus	155	
Folkestone, UK, Section		
Base cenomanian ammonites	38	
Inoc concentricus	0	10.5
Actinoceramus sulcatus	9.7	13
Anisoceras perarmatum	26	38
Arrhaphoceras substuderi	26	38
Callihoplites auritus	14.5	24.5
Callihoplites cantabrigense	25	
Callihoplites leptus	25	
Callihoplites tetragonus	26	38
Callihoplites vraconensis	26	38
Hyphoplites coelonotus	25	
Lepthoplites falcoides	26	38
Mortoniceras inflatum	14.5	25
Pleurohoplites renauxianus	26	38
Merstham, UK		
Anisoceras picteti	4.7	5
Callihoplites seeleyi	7	7.2
Callihoplites vraconensis	4.7	7.2
Idohamites elegantulus	4.7	5
Lechites gaudini		7
Lepthoplites falcoides	4.7	5
Lepthoplites pseudoplanus	4.7	7.2
Mortoniceras alstonensis	4.7	5
Mortoniceras fallax	4.7	5
Neophlycticeras blancheti	4.7	6.6
Ostlingoceras puzosianum	7	7.2
Pleurohoplites renauxianus	7	7.2
Harchies, Belgium		
Anisoceras perarmatum	-87.1	
Anisoceras pseudoelegans	-95.5	
Callihoplites vraconensis	-87.1	
Hamites virgulatus	-98.4	
Hyphoplites subfalcatus (ID cf.)	-86.1	
Lepthoplites cantabrigiensis	-102.1	
Pleurohoplites subvarians	-87.1	
Strépy, Belgium, Outcrop		
Callihoplites seeleyi	30	
Callihoplites pulcher	30	
Callihoplites tetragonus	20	
Cantabrigites subsimplex	30	
Hyphoplites valbonnensis	20	
Lechites gaudini		20
Mortoniceras fallax	20	
Neophlycticeras blancheti	20	
ANDRA MAR 203 Core, France		
Hamites virgulatus (ID cf.)	-523.23	
Hyphoplites coelonotus	-776.75	-523.38
Hyphoplites falcatus	-455.85	
Hyphoplites valbonnensis	-487.17	
Lechites gaudini	-487.17	
Mariella bergeri (ID cf.)	-467.25	
Ostlingoceras puzosianum	-561.54	
Pleurohoplites renauxianus	-581.8	
Schloenbachia varians	-430.8	
Diégo core, Madagascar		
Lechites gaudini	-50	
Mantelliceras mantelli	-23	-5
Mariella bergeri	-20	
Neostlingoceras carcitanense	-23	-5
Scaphites simplex	-54	
Sciponoceras roto	-23	-5
Stoliczkaia dispar	-50	
Biti breggiensis	-215	-118
Planomalina buxtorfi	-106	-10
Planomalina praebuxtorfi	-118	-90
Rota appenninica	-131	-10
Rota brotzeni	-23	-10
Rota globotruncanoides	-23	-10
Tici praeticinensis	-215	-180
Tici primula	-236	-135
Tici subticinensis	-215	-155
Tici ticinensis	-180	-106

Table 1: Biostratigraphic species and ranges in meters of each section from AMÉDRO (2008).

Integrated Upper Albian chronostratigraphy

Process of Graphic Correlation Experiment

To begin the GC experiment the Mont Risou section, southeastern France (GALE *et alii*, 1996; Fig. 2) was selected as the standard reference section because it records continuous basin deposition at a uniform rate of accumulation and it yields diverse ammonites, inoceramids, planktic foraminfera, and nannofossils. This section was cross plotted to itself setting its thickness in meters as the relative time scale. Subsequently seven other sections, which yielded precise and abundant biostratigraphic data, were plotted to it through multiple rounds and the ranges of the fossils extended to the thickness scale at Mont Risou. The first section plotted was the Kalaat Senan, Tunisia (AMÉDRO, 2008, Fig. 20), which spans from uppermost Albian to Cenomanian; this section also represents uniform deposition. The result is that the scale was extended from the base of the Upper Albian to the Cenomanian/Turonian contact.

The second graphed section was the Diégo well, N Madagascar (AMÉDRO, 2008, Fig. 22). This 300 m cored interval is mainly marl that spans an interval from lowermost Cenomanian to middle Albian (Fig. 3D). The section yields several key planktic foraminifera and in three samples a few ammonites. The LOC of the graph is constrained by a small number of first occurrences and it extends the bases of many foraminifera. The section appears to record continuous Late Albian deposition.

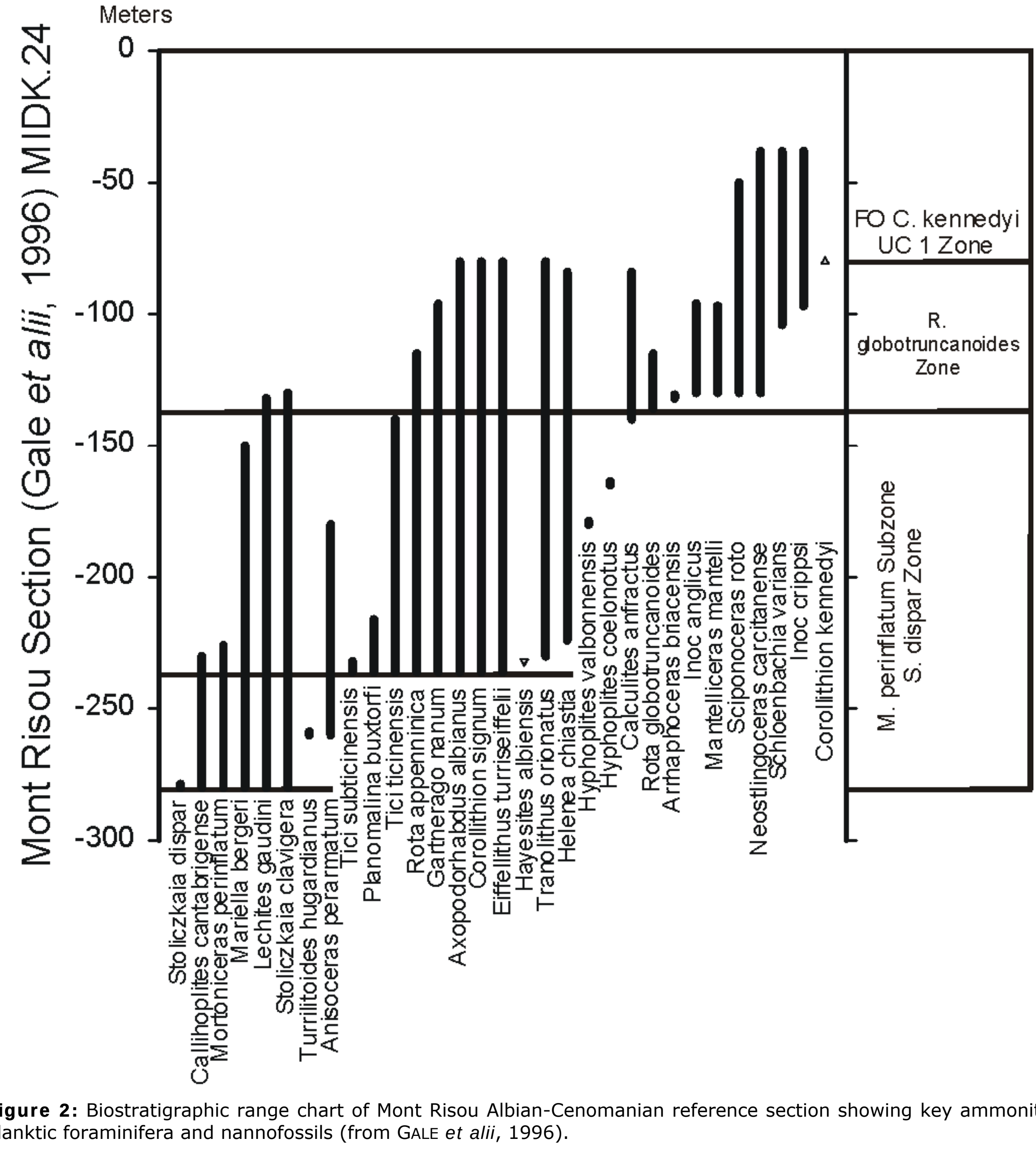

Figure 2: Biostratigraphic range chart of Mont Risou Albian-Cenomanian reference section showing key ammonites, planktic foraminifera and nannofossils (from GALE *et alii*, 1996).

The third section graphed was the cored interval in the ANDRA MAR 203 well (AMÉDRO, 2008, Fig. 8). This interval is about 560 m thick and spans from the Cenomanian to the Aptian stages (Fig. 3C). A significant unconformity, probably a sequence boundary, is at the base of the Albian Valbonne Formation (-827 m), which is a glauconitic sandstone that overlies Aptian marls. A second unconformity, a transgressive contact, is at the base of a phosphatic interval in the upper part of the Valbonne at -797.9 m. The Valbonne grades up into the Marcoule Formation. Biostratigraphic data appear 18 m above this upper break and span an interval about 350 m thick. In this section AMÉDRO placed the base of the 'Vraconnian' at the unconformity in the upper part of the Valbonne so that the 'Vraconnian' is 334 m thick. The LOC of the section is constrained by the FO and LO of *Hyphoplites coelonotus* and the LOs of three other ammonites (Fig. 3C). A short hiatus is suggested by the offset of the LOC in the basal Cenomanian. An alternative interpretation is that the interval recorded a reduced rate of sediment accumulation beginning in latest Albian times. At the Marcoule locality the complete section, from its base at -781 m to the base of the Cenomanian at about -464 m, correlates with zones XII-XIII in the near shore Folkestone section, where these same zones are only 13.8 m thick.

The fourth section to be added was the Mont Risou section in AMÉDRO (2008, Fig. 11), which was based on data from multiple sources including GALE *et alii* (1996). Thus the slope of the LOC is the same as that of the standard reference section. This plot is well constrained by several first and last occurrences; it extends some ranges and it adds three new species not found in other sections (Fig. 3A).

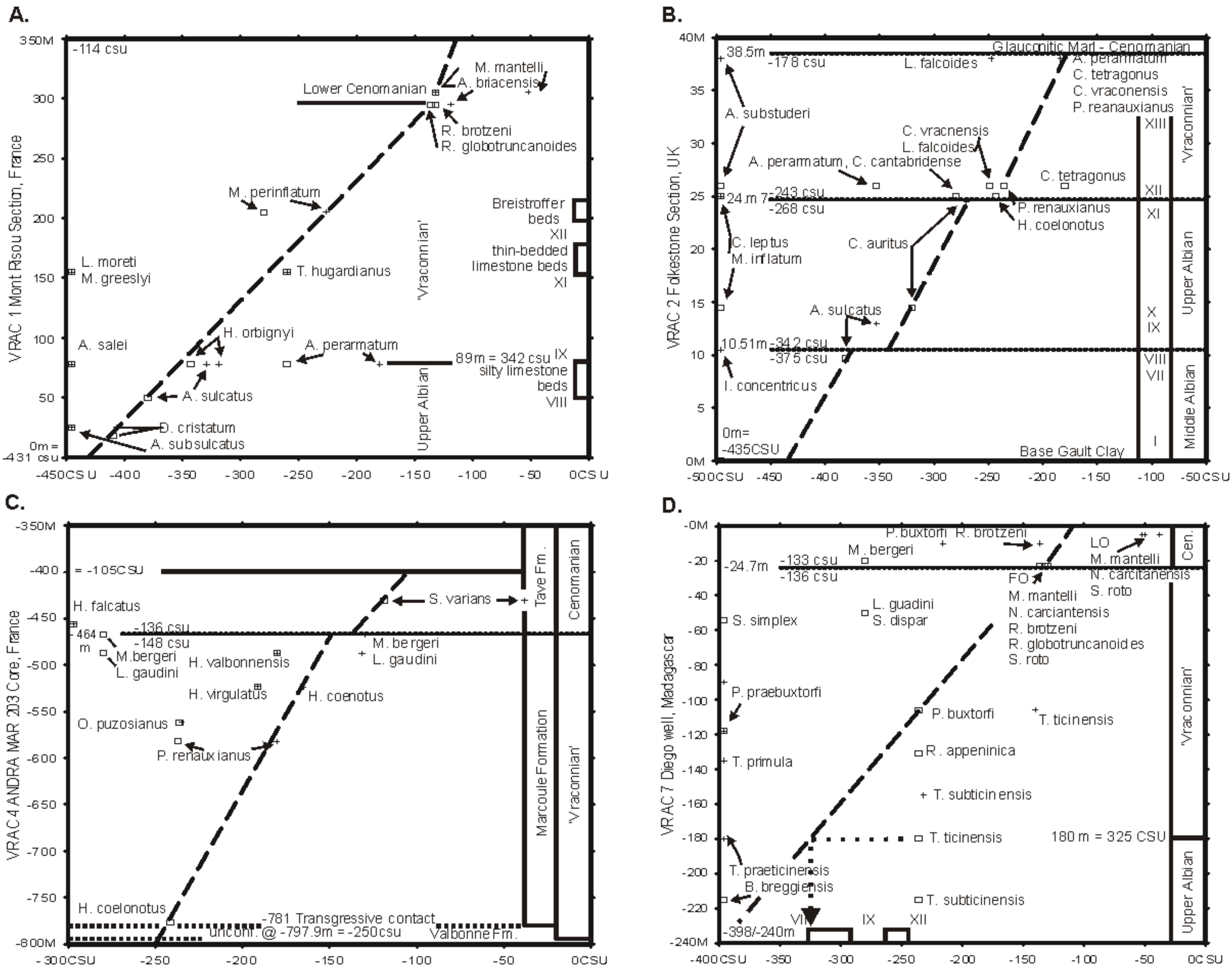

Figure 3: Graphic correlation interpretations of four key 'Vraconnian' sections. First occurrences (FO) of species are indicated by a square symbol (□) and the last occurrence (LO) by a plus sign (+). Superposed symbols of a species indicates a single occurrence. Symbols on the left of the Y axis indicate that the occurrence is only in the section they accompany. CSU is a composite standard unit calibrated in meters to the thickness of the Mont Risou section (file MIDK24). Horizontal solid and dotted lines are stratigraphic contacts; inclined dashed lines project a position in the section into the position of a species in the set of sections in the database of "Vraconnian" sections; these lines are 'lines of correlation' (LOC). Roman numerals indicate ammonite zones in the English sections.

The next section plotted was the Gault Clay in the Folkestone section in AMÉDRO (2008, Fig. 14). This section spans several significant unconformities (Fig. 3B), one at the base of the Gault Clay overlying the Lower Greensand, a second at the condensed interval VIII zone, a third at the XII zone, and the highest at the Albian/Cenomanian contact between the Gault and the glauconitic marl (HART, 2000). The LOC of the lower interval of zones I-VII is poorly constrained at the top by the FO of *Actinoceramus sulcatus* and its slope is the same as that of the higher LOCs. The unconformity break is placed at the top of zone VIII. The LOC in the next higher interval of zones IX-XI is constrained by the range of *Callihoplites auritus*. In the next higher section of zones XII-XIII the LOC is constrained by several FO and LO bioevents (Fig. 3B). This section plot defines the relative duration of the hiatus of two unconformities as meter thicknesses in the Mont Risou section; these intervals can now be projected into other graphed sections.

An older ammonite data set from Folkestone by AMÉDRO (1992) is graphed by several FO and LO's. The unconformities are well constrained as in the newer section in AMÉDRO (2008). The Merstham, England (AMÉDRO, 2008, Fig. 15) repeats the uppermost part of the Upper Greensand Formation that is present at Folkestone. The data are confined to two horizons so the LOC is not well constrained. However these data adjust nine FO's and nine LO's. The Strépy and Harches sections were graphed next (AMÉDRO, 2008, Fig. 17) and have limited data so that the LOC of each is not tightly constrained.

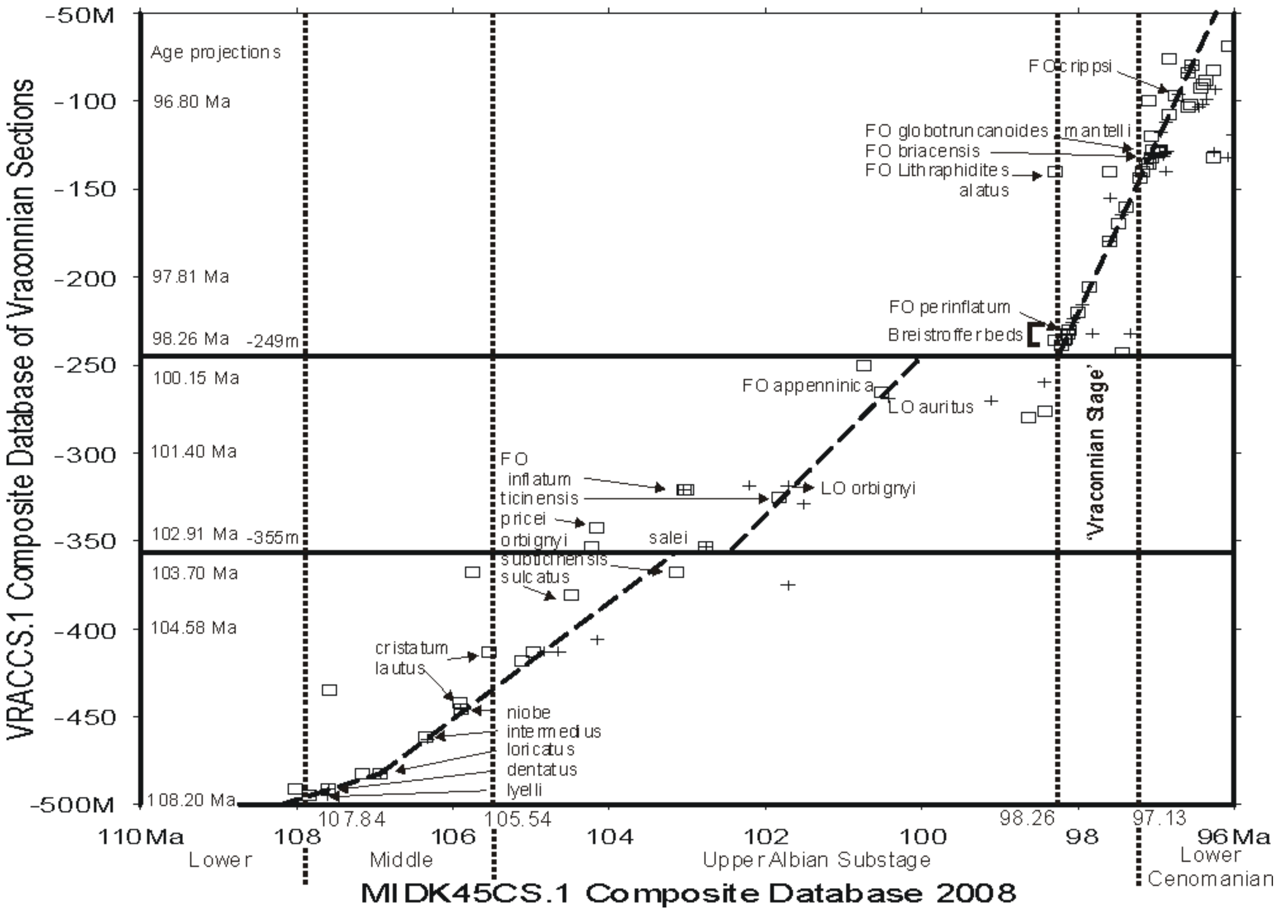

Figure 4: Graphic correlation plot of VRACCS.1 database to the global integrated MIDK45CS.1 database.

Process of calibration to numerical ages

The graphic correlation experiment resulted in a list of species and their ranges relative to each other in the metric scale of the Mont Risou section. The next step in the experiment was to convert the metric scale to a numerical age scale in mega-annum units. This was accomplished by plotting the composited range data set of AMÉDRO's 'Vraconnian' data set, VRACCS.1, to the MIDK45CS.1 composited range data set (Fig. 4). The MIDK45CS.1 data set is the next development stage beyond MIDK3 (SCOTT *et alii*, 2000) and MIDK42CS.1 (SCOTT, in press; see also data of MIDK42 on website precisionstratigraphy.com). It is composed of more than one hundred sections and nearly 3000 bioevents, geochemical events, magnetochrons, and sequence stratigraphic contacts. The scale of this range data set is the numerical time scale of HARLAND *et alii* (1990), as revised by OGG *et alii* (2004), with the exception of the age ascribed the base Cenomanian, 97.13 Ma, because correlations of radiometrically dated bentonites and bioevents have been re-evaluated (OBOH-IKUENOBE *et alii*, 2007).

The two unconformities in the uppermost Albian Upper Greensand Formation are well defined by the data plot (Fig. 4). The two hiatuses separate the VRACCS.1 section into three intervals; the lower break is at -355 meters and the upper break is at -249 meters, which is the base of the 'Vraconnian Stage'. The duration of the lower hiatus is 103.70 to 102.91 Ma, and that of the upper hiatus 100.15 to 98.26 Ma. The LOC of the lower interval is well constrained by numerous bioevents. This lower interval represents two rates of sediment accumulation, a slower basal interval and a faster upper interval. This rate change is indicated by the change in the LOC slope. The LOC of the middle interval is tightly constrained by ammonites and planktic foraminifera. The upper interval includes numerous bioevents and the LOC is very tightly constrained. The age of the 'Vraconnian Stage' spans from 98.26 to 97.13 Ma. The black shale, organic-rich BREISTROFFER marker beds were deposited at the beginning of the 'Vraconnian'.

Integrated biostratigraphic ranges

The stratigraphic ranges of 46 ammonites that were recorded in the seven key sections of AMÉDRO (2008) were integrated into a single range chart at the scale of the thickness of the Mont Risou section (Fig. 5). This scale was converted to a numerical age scale by graphing the composited VRACCS.1 data set to the MIDK45CS.1 data set as explained above. The three Middle Albian Substage zones are defined by the FO of the nominate species (Fig. 1 ; Table 2). The base of the Upper Albian Sub-stage is defined by the FO of *Dipoloceras cristatum*, which is the basal subzone of the Inflatum Zone. Two of the next overlying subzones are defined in this dataset by the FOs of *Hysteroceras orbignyi* and *Callihoplites auritus*; *Hysteroceras varicosum* is not included in this dataset. The base of *Stoliczkaia dispar* defines the base of the uppermost Upper Albian Dispar Zone.

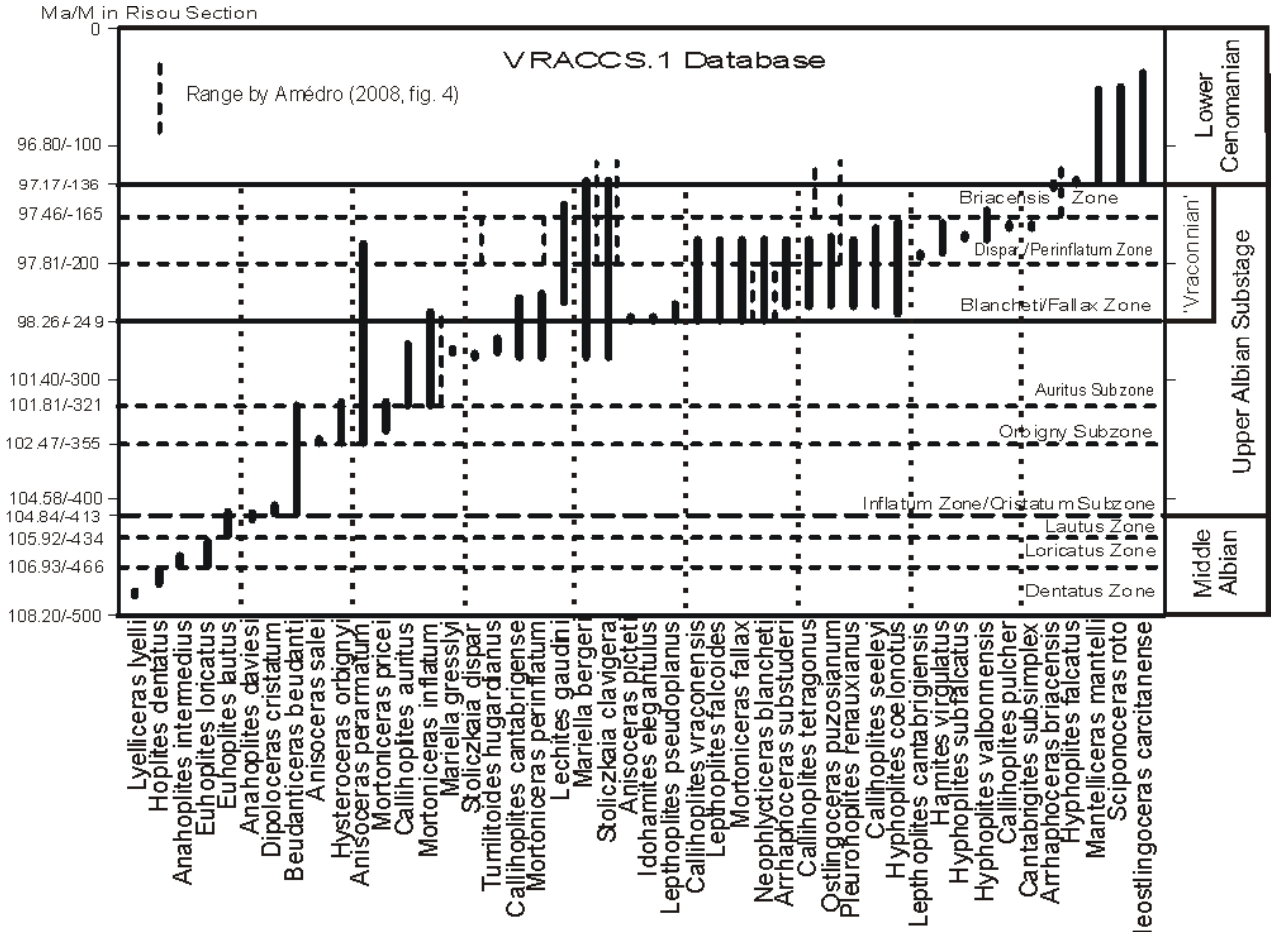

Figure 5: Chronostratigraphic range chart of ammonites in 'Vraconnian' composited database of key 'Vraconnian' sections. Ages interpolated by graphic correlation of the VRACCS.1 database with the MIDK45CS.1 database. The ages of some ranges are younger in the subset of 'Vraconnian' sections than in the complete set of sections in the MIDK45CS database used in Figure 7.

TAXA	VRACCS: FO - LO		MIDK45CS: FO - LO	
Acanthoceras amphibolum	65.0472	65.0472	94.3454	92.6212
Acanthoceras rhotomagense	5.9825	43.151	94.9483	92.5959
Actinoceramus subsulcatus	-406.00	-406.00	104.79*	104.79*
Actinoceramus sulcatus	-381.00	-329.0148	104.4776	101.5134
Algericeras boghariense	-103.4988	-93.7467	96.5874	96.2374
Algericeras proratum	-92.6427	-64.6744	96.4245	95.578
Amphizygus brooksii	-236.00	-80.00	124.717	65.505
Anahoplites daviesi	-414.8517	-410.6029	105.1156	104.8296
Anahoplites intermedius	-465.8373	-450.2584	107.1613	106.32
Anisoceras perarmatum	-353.00	-180.0123	98.426	97.5888
Anisoceras picteti	-248.88	-247.2	94.8091	94.3577
Anisoceras pseudoelegans	-188.2678	-188.2678	97.68*	97.68*
Anisoceras salei	-353.00	-353.00	102.7656	102.7656
Arrhaphoceras briacensis	-136.00	-132.00	97.0865	97.0865
Arrhaphoceras substuderi	-236.8768	-180.3551	98.18*	97.6*
Axopodorhabdus albianus	-236.00	102.7677	109.77	90.6992
Axopodorhabdus dietzmannii	-139.916	35.7909	128.6386	82.56
Beudanticeras beudanti	-410.6029	-321.1158	104.9638	103.0425
Biticinella breggiensis	-367.6759	-250.0185	105.757	97.5059
Calculites anfractus	-140.00	-84.00	97.1702	96.5842
Callihoplites auritus	-321.1924	-269.043	103.0146	100.4255
Callihoplites cantabrigense	-280.00	-230.00	98.6353	98.1121
Callihoplites leptus	-241.587	***	98.23*	***
Callihoplites pulcher	-170.00	-170.00	97.49*	97.49*
Callihoplites seeleyi	-236.00	-170.00	98.17*	97.49*
Callihoplites tetragonus	-236.8768	-180.00	98.18*	97.60*
Callihoplites vraconensis	-248.88	-180.0123	97.49*	97.60*
Cantabrigites subsimplex	-170.00	-170.00	97.49*	97.49*
Carbon peak OAE 2	100.9276	104.9757	93.52	93.45
Chiastozygus bifarius	-236.00	-84.00	98.1749	65.505
Chiastozygus litterarius	-236.00	-80.00	128.2573	65.5535
Chiastozygus platyrhethus	-236.00	-80.00	125.5054	88.3575
Corollithion kennedyi	-80.00	101.6637	96.55	92.00
Corollithion madagaskarensis	-236.00	-80.00	122.358	65.3262
Corollithion signum	-236.00	-80.00	114.0455	70.4437
Cretarhabdus conicus	-236.00	-80.00	133.1464	64.5992
Cretarhabdus striatus	-236.00	-80.00	117.1136	65.505
Cribrosphaerella ehrenbergii	-236.00	-80.00	116.0163	94.3685
Dicarinella algeriana	38.73	118.2239	95.105	89.7362
Dicarinella hagni	80.3194	118.2239	93.8363	89.1675
Dimorphoplites niobe	-449.5502	-436.8038	106.3502	105.8965
Dipoloceras cristatum	-413.00	-406.00	105.5386	104.1574
Discorhabdus ignotus	-236.00	-80.00	128.6386	65.505
Eiffellithus turriseiffelii	-236.00	-80.00	101.856	64.4399
Ellipsagelosphaera ovata	-216.00	-112.00	121.959	88.1021
Eprolithus apertior	-236.00	-80.00	121.1235	96.5423
Eprolithus floralis	-236.00	-84.00	122.8468	85.5995
Euhoplites lautus	-433.9713	-410.6	105.9188	104.6453
Euhoplites loricatus	-465.8373	-436.8038	106.9309	105.8965
Euhystrichoceras nicaisei	-103.4988	-19.04	96.5874	94.5395
Euomphaloceras septemseriatum	108.6557	108.6557	93.88	93.15
Favusella washitensis	-139.916	11.8706	114.1975	94.84
Forbesiceras beaumontianum	-127.8239	-128.8911	96.9524	96.2621
Gartnerago nanum	-236.00	-96.00	98.296	94.23
Gartnerago obliquum	107.1837	128.16	99.2536	64.743
Gartnerago praeobliquum	-84.00	***	96.5842	***
Gartnerago stenostauron	-139.916	-128.3391	97.588	96.864
Gartnerago theta	-108.00	-80.00	96.8353	89.0722
Graysonites azregensis	-127.82	-127.2379	96.95*	96.94*
Graysonites cobbani	-126.0738	-122.2903	96.92*	96.87*
Hamites virgulatus	-191.1179	-165.9805	97.71*	97.45*
Hayesites albiensis	-232.00	***	118.6477	97.3296
Hedbergella libyca	-236.00	-212.00	100.6217	94.66
Helenea chiastia	-224.00	102.7677	133.9695	92.7
Helicolithus trabeculatus	-236.00	-80.00	122.8533	65.505
Hoplites dentatus	-472.9187	-465.8373	107.5987	106.93
Hyphoplites coelonotus	-242.942	-165.00	97.4319	97.4319
Hyphoplites falcatus	-132.0523	-132.0523	96.2621	96.08
Hyphoplites subfalcatus	-179.0295	-179.0295	97.51*	97.51*
Hyphoplites valbonnensis	-180.00	-155.0337	97.5888	97.5888
Hypoturrilites gravesianus	-128.8911	-112.3309	96.9684	94.84
Hypoturrilites schneegansi	-127.8239	-98.9	96.9524	96.3536
Hysteroceras orbignyi	-353.00	-318.414	104.226	101.71
Idohamites elegantulus	-248.88	-247.2	98.31*	98.29*
Inoceramus anglicus	-130.00	-96.00	104.1574	96.7098
Inoceramus concentricus	-435.00	-375.0571	107.5807	101.71
Inoceramus crippsi	-97.00	-38.00	96.7471	94.2
Lechites gaudini	-236.00	-151.2174	98.6353	96.9133
Lechites moreti	-276.00	-276.00	98.59*	98.59*
Lepthoplites cantabrigiensis	-194.7543	-194.7543	97.75*	97.75*
Lepthoplites falcoides	-248.88	-180.3551	98.58*	98.31*
Lepthoplites pseudoplanus	-248.88	-234.88	98.31*	98.16*
Lithraphidites acutus	-90.8027	101.6637	96.3969	92.7
Lithraphidites alatus	-139.916	-105.5228	98.296	93.2
Lithraphidites carniolensis	-236.00	-80.00	134.1294	65.4901
Lithraphidites pseudoquadratus	-236.00	21.0707	98.1749	93.87
Lyelliceras lyelli	-475.7512	-475.7512	107.84	107.5987
Manivitella pemmatoidea	-236.00	-80.00	133.9695	65.2514
Mantelliceras dixoni	-41.4901	-41.49	95.6585	95.4
Mantelliceras mantelli	-132.00	-38.00	97.0656	95.65
Mantelliceras saxbii	-127.8239	-54.0022	96.9643	95.5
Mariella bergeri	-280.00	-129.6378	98.6353	96.8887
Mariella cenomanensis	-127.8239	-112.3952	96.9524	95.7203
Mariella gresslyi	-276.00	-276.00	98.59*	98.59*
Markalius circumradiatus	-228.00	-80.00	134.0985	82.2933
Marker bed Breistroffer	-235.00	-224.00	98.1644	98.0493
Mojsisovicsia subdelaruei	-436.8038	-436.8038	105.8965	105.8965
Mortoniceras alstonensis	-248.88	-247.2	98.31*	98.29*
Mortoniceras fallax	-248.88	-180.00	98.31*	97.58*
Mortoniceras inflatum	-321.1158	-241.59	103.0425	99.1149
Mortoniceras perinflatum	-280.00	-226.00	98.6353	98.0702
Mortoniceras pricei	-342.7298	-318.414	104.1574	102.1977
Neolobites vibrayeanus	101.6637	102.7677	93.7514	93.12
Neophlycticeras blancheti	-248.88	-180.00	98.31*	97.58*
Neostlingoceras carcitanense	-132.00	-38.00	97.0656	96.1028
Ostlingoceras puzosianum	-236.00	-129.6378	98.17*	96.97*
Oxytropidoceras roissyanum	-472.9187	-472.9187	108.0147	107.58
Percivalia hauxtonensis	-144.00	-144.00	97.2121	93.47
Placozygus fibuliformis	-230.00	-80.00	98.1121	65.505
Planomalina buxtorfi	-236.00	-119.00	100.606	96.0093
Planomalina praebuxtorfi	-250.0185	-216.0556	100.7341	97.9467
Pleurohoplites renauxianus	-236.8768	-180.3551	98.18*	97.60*
Pleurohoplites subvarians	-180.0123	-180.0123	97.59*	97.59*
Praeglobotruncana delrioensis	-222.9565	101.6637	108.0343	92.00
Praeglobotruncana stephani	-235.7826	118.2239	100.509	90.41
Prediscosphaera columnata	-236.00	-80.00	122.8533	90.7
Prediscosphaera cretacea	-84.00	-80.00	119.3508	64.523
Prediscosphaera spinosa	-220.00	-80.00	121.9656	64.4953
Pseudaspidoceras flexuosum	109.7598	109.7598	93.044	93.00
Quadrum gartneri	107.1837	128.16	93.5451	68.3833
Rhagodiscus achlyostaurion	-236.00	-80.00	124.6741	92.00
Rhagodiscus angustus	-236.00	-80.00	123.278	65.505
Rhagodiscus asper	-236.00	-80.00	128.6386	92.95
Rhagodiscus splendens	-228.00	-80.00	123.278	65.551
Rotalipora appenninica	-265.787	23.6467	100.5159	94.48
Rotalipora brotzeni	-136.00	-119.00	97.0842	94.62
Rotalipora cushmani	33.9508	101.6637	96.17	93.07
Rotalipora deeckei	23.6467	37.9989	95.3597	93.2
Rotalipora evoluta	-139.916	-52.1622	97.588	95.05
Rotalipora gandolfi	-222.9565	88.7835	98.9078	93.52
Rotalipora globotruncanoides	-136.00	101.6637	97.13	93.15
Rotalipora greenhornensis	-100.0028	99.8236	97.0842	93.07
Rotalipora montsalvensis	-59.5223	101.6637	97.384	93.15
Rotalipora reicheli	-1.0096	32.1108	96.706	94.42
Rotelapillus crenulatus	-236.00	-80.00	124.612	65.597
Rotelapillus laffittei	-224.00	-80.00	134.0402	66.407
Scaphites simplex	-172.3889	***	97.51*	***
Schloenbachia varians	-119.9188	-38.00	97.0648	95.12
Sciponoceras roto	-132.00	-50.00	97.0656	96.2284
Sharpeiceras laticlavicum	-76.0825	-42.2261	96.8389	95.45
Sharpeiceras schlueteri	-127.8239	-103.4988	96.9524	96.4478
Staurolithites glaber	-232.00	-112.00	98.133	96.8772
Stoliczkaia africana	-222.9565	-131.2738	98.04*	97.00*
Stoliczkaia clavigera	-280.00	-132.00	98.6353	97.0656
Stoliczkaia dispar	-280.00	-280.00	98.6353	97.116
Stoverius achylosus	-172.00	-80.00	123.3079	97.116
Tegumentum stradneri	-230.00	-80.00	129.3543	83.3875
Tetrapodorhabdus coptensis	-230.00	-80.00	128.4545	93.05
Ticinella praeticinensis	-367.6759	-325.2222	110.9318	97.4606
Ticinella primula	-393.1481	-270.6389	111.614	97.3667
Ticinella subticinensis	-367.6759	-232.00	103.1399	97.82
Ticinella ticinensis	-325.2222	-140.00	101.8279	96.8779
Tranolithus gabalus	-230.00	-80.00	123.9877	83.5584
Tranolithus minimus	-220.00	-132.00	98.0074	65.505
Tranolithus orionatus	-230.00	-80.00	110.9137	69.1743
Turrilites acutus	26.5908	71.6713	94.64	93.98
Turrilites costatus	-23.8259	26.5908	95.3943	94.14
Turrilites scheuchzerianus	-14.8097	-0.6416	96.1343	94.07
Turrilitoides hugardianus	-276.00	-260.00	98.426	98.426

Table 2: Biostratigraphic ranges of Albian Stage ammonites, planktic foraminifera and nannofossils zones in 'Vraconnian' sections in metric units in the Mont Risou section (VRACCS.1) and numerical ages in the global MIDK45CS.1 database; ages with asterisk are interpolated by plotting the 'Vraconnian' database, VRACCS.1 to the MIDK45CS.1 database.

AMÉDRO (2008) proposed that the base of the 'Vraconnian Stage' be defined by the FOs of *Mortoniceras fallax* and *Neophlycticeras blancheti*. He included three ammonite zones in this stage in ascending order: *Mortoniceras* (*Mortoniceras*) *fallax* Interval Zone, *Mortoniceras* (*Subschloenbachia*) *perinflatum* Total Range Zone, and the *Arrhaphoceras* (*Praeschloenbachia*) *briacensis* Interval Zone (Fig. 1). The composited dataset of his sections shows that *M. inflatum* first appears lower in the section than *M. fallax* (Fig. 5) because GALE *et alii* (1996) reported it lower in their Mont Risou section than did AMÉDRO (2008, Fig. 11). The FO of *A. briacensis* is at the base of the Cenomanian Stage based on this set of sections. The ranges of AMÉDRO's key zonal species (AMÉDRO, 2008, Fig. 4) are dashed lines on Fig. 5 ; some ranges are similar and others are quite different from the ranges derived by graphic correlation of his data. *S. dispar* has a short range because it occurs in two sections, the Diégo well and GALE's *et alii* Mont Risou section. Both *Mariella bergeri* and *Stoliczkaia clavigera* are low in the Mont Risou section (GALE *et alii*, 1996). Some species have longer ranges in AMÉDRO's dataset because they occur with species of other zones in condensed intervals in other sections not graphed, such as at the 'Vraconnian' stratotype (RENZ & JUNG, 1978) and near Drap in the Alpes-Maritimes, France (DELANOY & LATIL, 1988).

This graphic correlation experiment shows that the base of the *S. dispar* Zone and the FO of *M. perinflatum* are significantly lower (31 m) and older (380 kyr) than the FO of either *M. fallax* or *N. blancheti*. Thus the concept of a 'Vraconnian Stage' is not equal to the Dispar Zone. However the FOs of *M. perinflatum*, *M. fallax*/*N. blancheti*, and *A. briacensis* may be used to divide the Dispar Zone into three subzones.

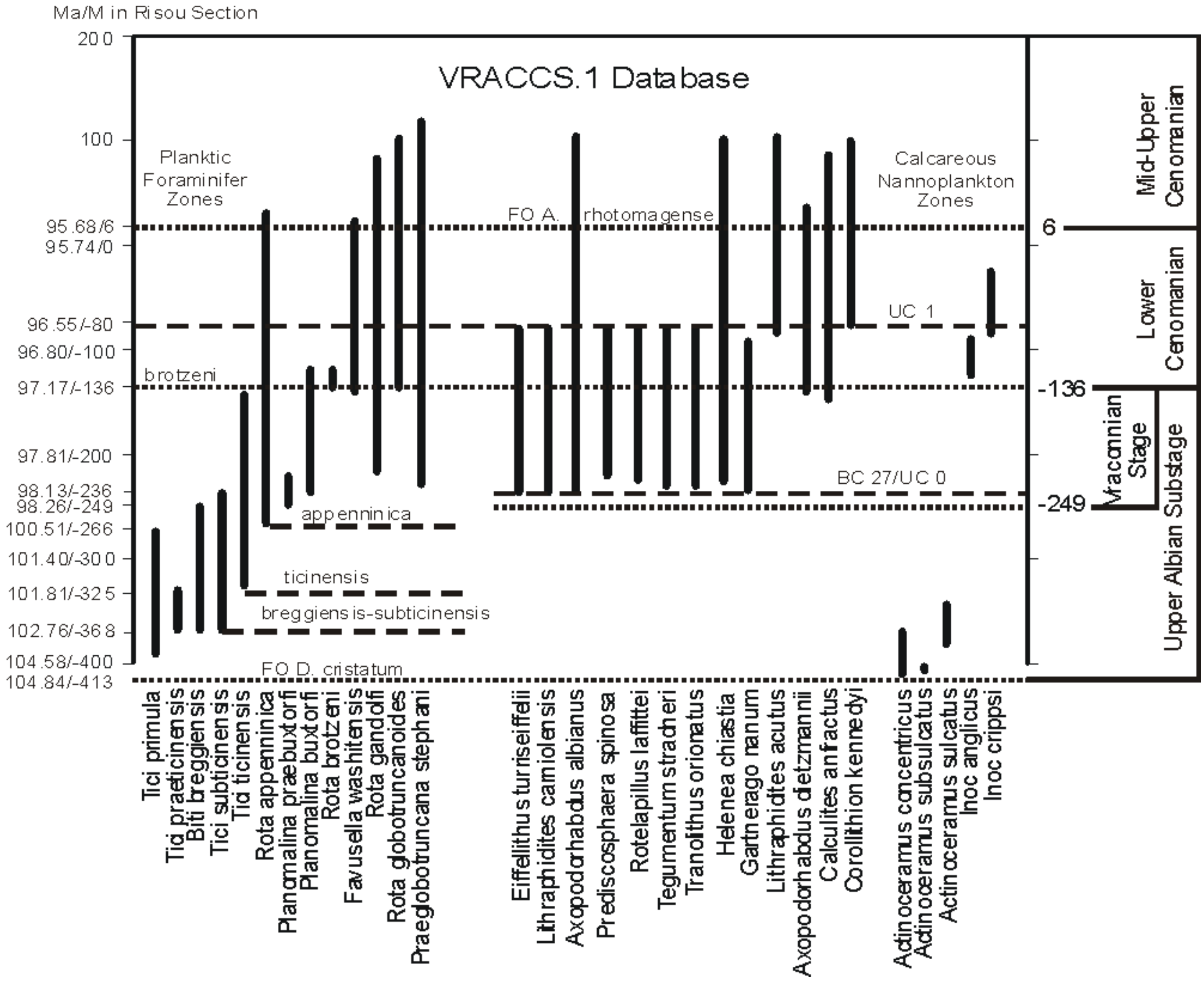

Figure 6: Chronostratigraphic range chart of planktic foraminifera, calcareous nannofossils, and inoceramids in 'Vraconnian' composited database of key 'Vraconnian' sections. Vertical axis is meters in the Mont Risou section. Ages in Ma are interpolated by graphic correlation of the VRACCS.1 database with the MIDK45CS.1 database. Highest part of composite section not converted to ages. Foraminifer zones are defined by FO of named taxa. Nannofossil zones are defined by FO of *E. turriseiffelii* and *C. kennedyi* respectively. The FO of *Lithraphidites acutus* is in the middle part of the range of the Lower Cenomanian ammonite *Mantelliceras mantelli* in the Kalaat Senan section, Tunisia and 103.5 m above the base of *Rotalipora globotruncanoides* (MIDK.10 section; ROBASZYNSKI *et alii*, 1994).

Integration of key planktic foraminifera and calcareous nannofossils (Fig. 6) based on the limited dataset of AMÉDRO (2008) shows that *R. appenninica* is below the base of *Mortoniceras fallax*, and the first occurrence of *E. turriseiffelii* is slightly above it. In the larger MIDK45 data-set the FO of *E. turriseiffelii* is projected at 101.86 Ma and *R. appenninica* at 100.37 Ma, both of which are significantly older than the FO of *M. fallax* at 98.26 Ma. So neither pelagic species is useful as a proxy guide to the base of a 'Vraconnian Stage.'

Five inoceramid species are recorded in the sections at Mont Risou and at Folkestone (Fig. 6). *Actinoceramus concentricus*, *Actinoceramus sulcatus*, and *Actinoceramus subsulcatus* characterize the lower part of the Upper Albian and *Inoceramus anglicus* and *Inoceramus crippsi* characterize the Lower Cenomanian.

The Albian stage is divided into seven zones and twenty-five subzones. The ranges of key fossils that define these zones can be calibrated to numerical Ma ages by graphic plots to sections bearing dated bentonites and geo-chemical events. This process measures the durations of the zones as proposed by AMÉDRO and ROBASZYNSKI (2008). This database is anchored to bentonites in the U.S. Western Interior dated by OBRADOVICH (1993) and projected to the age of Magnetochron M0 at the base of the Aptian. As new radiometric ages are accrued this database can be tested and adjusted to accommodate new data.

Albian	Upper		S. (F.) blancheti	98.26*	M. fallax	98.26*	R. appenninica 100.52	
		M. inflatum	C. auritus	103,01	M. inflatum	98,64		
			H. varicosum	103,03	M. pricei	104,16	R. ticinensis 101.83	E. turriseiffelii 101.91
			H. orbignyi	104,23			B. breggiensis 105.76	E. monechiae 101.97
			D. cristatum	105,54	D. cristatum	105,54		
	Middle	E. lautus 106.23	A. daviesi	105,68				
			E. nitidus	105,78				
		E. loricatus 107.16	E. meandrinus	NA				
			M. subdelaruei	105,9				
			D. niobe	106,35				
			A. intermedius	107,16				
		H. (H.) dentatus 107.60	H. (H.) spathi	107,6				
			L. lyelli	107,84				
	Lower	D. mammillatum 111.58	L. pseudolyelli	NA				
			P. (I.) steinmanni	108,2				
			O. bulliensis	109,47				
			P. puzosianus	110,8				
			O. raulinianus	109,39				A. albianus 109.77
			C. floridum	111,31			T. praeticinensis 110.93	T. orionatus 110.91
			S. kitcheni	NA			T. primula 111.61	
			D. periinflata	NA				
		L. tardefurcata	L. (N.) regularis	110,94				
			L. tardefurcata	112,66				
			L. schrammeni	NA			H. planispira 129.19	C. signum 114.05

Figure 7: Chronostratigraphic chart of the original Albian Stage. Ammonite zones from OGG *et alii* (2004), HOEDEMAEKER *et alii* (2003), HOEDEMAEKER & RAWSON (2000), HOEDEMAEKER *et alii* (1993), HANCOCK (1991), and OWEN (1984a, 1984b). Planktic foraminifera zones based on FOs from PREMOLI SILVA & SLITER (2002). Nannofossil zones based on FOs from BOWN *et alii* (1998) and BRALOWER *et alii* (1995). Numerical ages interpolated by graphic correlation of MIDK45 database (SCOTT *et alii*, 2000). NA indicates species not in the MIDK45 database.

Chronostratigraphic correlation of key sections

The graphic correlation method provides data for chronostratigraphic correlation of the key 'Vraconnian' sections (Fig. 8). The proposed 'Vraconnian Stage' correlates with the upper part of the Upper Albian Substage (Fig. 4). The cross section datum is the Albian/Cenomanian stage boundary as defined by the FO of *R. globotruncanoides*. AMÉDRO used the FOs of *Mortoniceras fallax* and *Neophlycticeras blancheti* to define the base of the 'Vraconnian', which is approximated by the -250 m position in the VRACCS.1 database. This position correlates with the unconformity at the base of zones XII-XIII in the Folkestone section and with the transgressive facies between -800 and -781 m in the MAR 203 core at Marcoule. The same time line also correlates within the low-stand limestone bundles in the Mont Risou and Diégo core. The entire interval of the Bracquegnies Formation in the Strépy boatlift section and in the Harchies N° 1 well (AMÉDRO, 2008, Fig. 17) correlates with Folkestone zones XII-XIII. The organic-rich BREISTROFFER interval in the Mont Risou section lies within the lower part of the transgressive interval equivalent to zone XII; it may represent maximum flooding. In the

Mont Risou section a lower bundle of bioclastic-glauconitic limestone from about 50 to 80 m (AMÉDRO, 2008, Fig. 11) correlates with the lower condensed section between zones VIII and IX at Folkestone.

The thickness of the 'Vraconnian Stage' varies greatly among the sections as noted by (AMÉDRO, 2008). In the MAR 203 core at Marcoule the equivalent 'Vraconnian' interval is 317 m thick, eight times than thicker than at the Strépy section, more than twenty-three times thicker than at Folkestone, and nearly 160 times thicker than in the 'Vraconnian' reference section in Switzerland. The rates of sediment accumulation varied from 4.5 m/myr at Folkestone to 37.6 m/myr at Mont Risou, and 111.6 m/myr at Marcoule. The rate of accumulation is based on the compacted section and is not a sedimentation rate. These rates are based on the duration of about 3 myr for the 'Vraconnian' interval. This great range in rates is based on very different basin subsidence histories and tectonic conditions of each section.

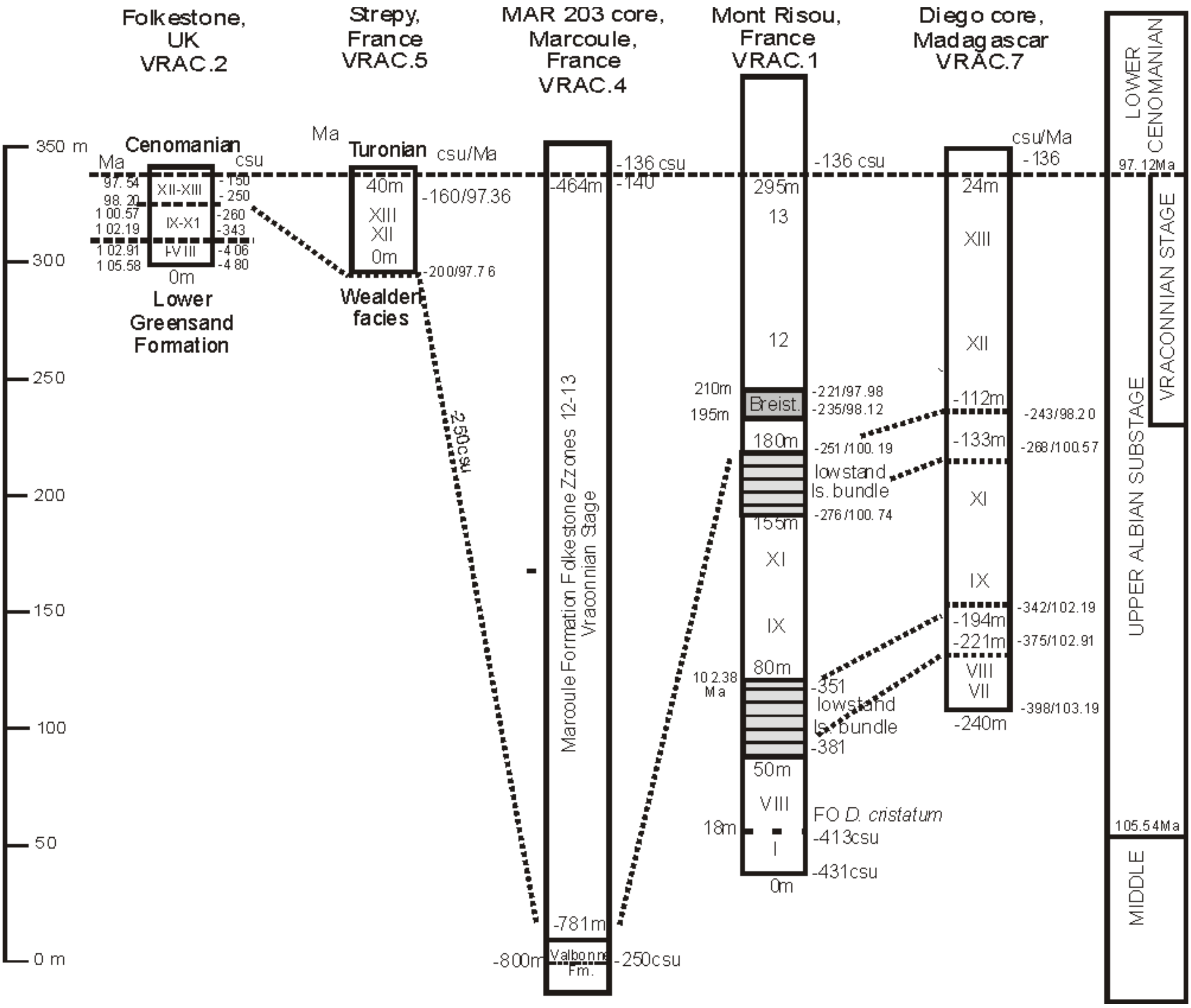

Figure 8: Stratigraphic correlation of key 'Vraconnian' sections using base of Cenomanian Stage as datum. CSU values are meters in the Mont Risou section of GALE *et alii* (1996, MIDK.24). Ages interpolated by graphic correlation of the VRACCS.1 database with the MIDK45CS.1 database. Age of lower part of Valbonne Formation below intra-formational unconformity at -800 m not projected because of the absence of fossils.

Re-examination of the rationale for a 'Vraconnian Stage'

1. The interval is mappable

This criterion is essential to the definition of lithostratigraphic units such as formations (NACSN, 2005). However, it is not part of the definition of a stage, in which lithofacies change from basin to basin. The lithologies that comprise the 'Vraconnian' interval are quite different from section to section (AMÉDRO, 2008), and thus do not make up a mappable lithostratigraphic unit.

2. The interval records an important eustatic event

Indeed the 'Vraconnian' interval records a third-order three myr depositional cycle of transgression and regression on a regional even global scale. This feature, however, defines sequence stratigraphic units, not stages (NASCN, 2005). The Upper Albian Stage records five such sequences of this scale (SCOTT *et alii*, 2003), but it would be impractical to divide the Albian into five stages.

3. The interval has a distinctive and diverse fossil assemblage

This property is an essential feature of a stage concept. Three species of *Mortoniceras* and one species of *Stoliczkaia* comprise the 'Vraconnian Stage' according to AMÉDRO (2008) and AMÉDRO & ROBASZYNSKI (2008). AMÉDRO (2008) characterizes the 'Vraconnian' by the abrupt diversification of heteromorph ammonites of the Turrilitidae, Hamitidae, Anisoceratidae, and Baculitidae in the condensed La Vraconne section, where they comprise 60% of the specimens. However, species of three of these families appear earlier in the Late Albian between 102.47 and 98.64 Ma (Fig. 5) earlier than the FO of *Mortoniceras fallax* and *Neophlycticeras blancheti*.

The three heteromorph species restricted to the 'Vraconnian' in AMÉDRO's database (2008) are primarily found in Western Europe. In the Carpatho-Balkan region of Eastern Europe the 'Vraconnian' is represented by a condensed interval of glauconitic and phosphatic sandy limestone less than one meter thick; the only ammonite species of the zone is *Stoliczkaia notha* (KUTEK & MARCINOWSKI, 1996). One North American section, Dry Creek in northern California (AMÉDRO, 2008, Fig. 24), yields three ammonite species of the Dispar Zone, only one of which, *Lechites gaudini*, is found at the type section of the 'Vraconnian' in Switzerland (RENZ & JUNG, 1978). Few species characteristic of the 'Vraconnian' are found outside of Western Europe. The ammonite assemblage is not widespread in the Tethyan or Boreal Realms.

4. The interval duration is similar to that of other stages

The proposed duration of the 'Vraconnian Stage' is 2-3 myr, which is equivalent to that of the Santonian Stage. However the durations of Cretaceous stages vary from 2.3 to 13 myr (OGG *et alii*, 2004) and duration is not a criterion for defining a stage.

5. The interval locally is quite thick

Sections bearing the 'Vraconnian' fauna are locally thicker than the underlying part of the Albian. The thickness difference is highly variable from basin to basin and within basins. Such thickness differences are found between condensed sections and coeval basin margin and basin center sections of many zones.

Conclusions

The diverse ammonite assemblage in the uppermost part of the Upper Albian Substage comprises a distinctive zone in Western Europe that can be subdivided into three subzones. These subzones are recognized in many Tethyan and transitional Boreal sections in Europe. However, at the 'Vraconnian' type section in Switzerland *Stoliczkaia dispar* and *Mortoniceras perinflatum* are the only zonal named taxa present. The strata bearing the *S. dispar* Zone are bounded by unconformities in many sections and they are but one of five Upper Albian depositional sequences. The thickness of this sequence varies from condensed sections of two meters to expanded basinal sections more than 300 meters thick. The *S. dispar* Zone represents a time interval of about three myr, which is about the same duration as the briefest Cretaceous ages. This interval is very useful as a biostratigraphic unit and a third-order sequence stratigraphic unit. However this interval is not a practical chronostratigraphic unit such as a stage because its boundaries cannot be demonstrated to be synchronous and the interval is not isochronous, nor is it globally recognizable. Defining this interval as a stage equivalent to the Albian and Cenomanian stages would materially alter the concept of the Albian Stage by deleting its uppermost zone. The concept of a 'Vraconnian Stage' is not a practical subdivision of the Cretaceous System.

Acknowledgments

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