Revised radiolarian ages for the sedimentary cover of the Balagne ophiolite (Corsica, France). Implications for the palaeoenvironmental evolution of the Balano-Ligurian margin

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**Key-words** – Corsica, Radiolaria, Ophiolites, Ligurian ocean, Balagne nappe, Jurassic

**Abstract.** – The age of radiolarites covering the Balagne ophiolite is reassessed based on new and revised radiolarian fossil evidence. The oldest radiolarian cherts are dated as upper Bathonian-lower Callovian in two tectonic units: San Colombano and Novella. These are amongst the oldest ages available so far from ophiolites of the Ligurian ocean. An important stratigraphic gap, spanning the Callovian-early Kimmeridgian interval, is specified between radiolarites and the overlying (and locally gullying) San Colombano shallow-water limestones (sub-unit I). We can now specify that radiolarian ooze accumulated until the late Kimmeridgian in the distal parts of the Balagne margin (sub-unit SC III and Novella unit), while fragments of Hercynian basement fell into the Balagne basin during the late Kimmeridgian-Tithonian.

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**INTRODUCTION**

The geological history of Corsican ophiolite units is linked to the evolution of the Jurassic Ligurian ocean. Despite its relatively small size (150-200 km-wide, according to Principi et al. [2004]), the timing of the opening, quiescence and closure of this ocean are key to our understanding of the Mesozoic evolution of the greater area between Europe and Africa [Abbate et al., 1994a,b]. Radiolarian biochronology has played a vital role over the last twenty years in unraveling the geodynamic and palaeoenvironmental evolution of Tethyan oceanic realms and continental margins (Baumgartner 1984, 1990; De Wever and Dercourt, 1985; De Wever et al., 1985, 1994; Karakitsios et al., 1988; Danelian and Robertson, 1997; Danelian et al., 2004).

This study is based on samples collected in 1985 from the Balagne nappe of Corsica (fig. 1A), preliminary results of which were published shortly afterwards. These suggested essentially Late Jurassic ages [De Wever et al., 1987], in agreement with parallel radiolarian studies by Conti et al. [1985].

The biochronological potential of Middle-Late Jurassic Radiolarians greatly improved following the publication of a new Tethyan biozonation by the INTERRAD Jurassic-Cretaceous Working Group [Baumgartner et al., 1995a]. It gave the impetus to revise radiolarian ages for the sedimentary cover of Ligurian ophiolites in Corsica [De Wever and Danelian, 1995] and suggested the presence of both Middle and Upper Jurassic radiolarites. More recently, as part of a continuous effort to date more precisely the opening history

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**Ages révisés à partir des radiolaires pour la couverture sédimentaire des ophiolites de Balagne (Corse, France). Implications pour l’évolution paléoenvironnementale de la marge Balano-Ligure**

**Mots-clés.** – Corse, Radiolaires, Ophiolites, Océan ligure, Nappe de Balagne, Jurassique

Résumé. – L’âge des radiolaires surmontant les ophiolites de la nappe de Balagne est re-évalué à partir de données nouvelles et révisées sur des radiolaires. Les radiolaires les plus anciennes, d’âge bathonien supérieur à callovien inférieur, sont datées au sein de deux unités tectoniques: San Colombano et Novella. Cette fourchette d’âge est une des plus anciennes parmi les âges disponibles pour les ophiolites de l’océan ligure. Un hiatus stratigraphique important, couvrant l’intervalle Callovien à Kimméridgien inférieur, est mis en évidence entre les radiolaires et les calcarénites de San Colombano (sous-unité I) les surmontant sans discordance avec un contact stratigraphique, localement ravinant. On peut aussi maintenant préciser que, dans les imbrications de la nappe de Balagne plus éloignées de la marge (sous-unité III de San Colombano et unité de Novella), de la boue à radiolaires s’accumulait jusqu’au Kimméridgien supérieur, des débris de roches du socle hercynien étant transportés dans le bassin de Balagne durant le Kimméridgien supérieur-Tithonien.
of the Ligurian ocean, Chiari et al. [2000] and Bill et al. [2001] revised the radiolarian ages available in Corsica [Conti et al., 1985; De Wever et al., 1987].

Since hydrofluoric acid (HF) leaching only etches a thin veneer of the external part of processed chert, we decided to reprocess some fertile samples and re-examine identifications and ages of old and new radiolarian material from Corsica. Our results further specify the age of oceanic crust preserved within the Balagne nappe and provide an improved chronostratigraphic framework for the sedimentary and palaeoenvironmental evolution of the Balano-Ligurian margin.

GEOLOGICAL AND STRATIGRAPHIC FRAMEWORK

The sedimentary sequence of the Balagne nappe (fig. 1B) accumulated on the oceanic crust of the Ligurian ocean, represented essentially by extensive outcrops of ophiolitic lavas and to a much lesser extent, by gabbros and peridotites [Durand-Delga, 1986; Rossi et al., 2001]. The first sedimentary rocks covering the lavas consist of radiolarites, which are usually 10-30 m-thick, but in places may be much reduced or even absent. Radiolarites are locally overlain by several tens of meters of bioclastic-oolithic limestone (San Colombano Limestone) and limestone breccias. Thinly bedded limestones with calpionellids, overlain by siliceous-calcareous shales with carbonate lenses (“Palombini”-like San Martino Formation), cap the Jurassic sequence.

The geology of the Balagne nappe is presented in the map prepared by Nardi et al. [1978] and more recently by Rossi et al. [2001]. Structurally, the Balagne nappe is composed of a number of tectonic units, stacked as follows from base (in the NW) to top (in the SE) (fig. 2a-b):

- a) the Annunciata unit (coarse grain Eocene flysch);
- b) the Toccoone unit (“flysch à lydiennes” of Albian-Cenomanian age);
- c) the San Colombano unit, which will be studied here in further detail;
- d) the Alturaja unit (upper Cretaceous sandstones and conglomerates);
- e1) the ophiolitic thrust sheet of Cima d’Aghio-Servadio;
- e2) the large tectonic unit of Novella (pillow lavas and their, mainly Cretaceous, sedimentary cover).

Tectonic units c and e contain thick pillow-lavas overlain by radiolarites.

The unit of San Colombano (SC) is subdivided into three stacked sub-units (fig. 3A). The two lower ones (SC I and SC II) display a fairly similar sequence. In sub-unit SC II, the 20 m-thick San Colombano Limestone overlies stratigraphically undated radiolarites. It is composed of shallow-water limestones (often oolitic), which locally contain black silicified layers and benthic Foraminifera of Kimmeridgian age [Peybernès in Guérin, 1984; Peybernès et al., 2001]. Further up the sequence, the San Colombano Limestone is overlain (with a stratigraphic contact) by a 10 m thick sequence of massive calcarenite-breccias, rich in blocks and debris of rocks from the Hercynian basement (Permian volcanics, granites and metamorphic rocks; Durand-Delga et al. [1997]). They contain the same Kimmeridgian microfauna, which was probably re-deposited.

In sub-unit SC I, ca. 300 m to the north-east of Grand Rocher (San Colombano castle), ca. 5 m of dark colour radiolarites form the base of the sedimentary cover of spilitic pillow lavas. Samples 85C-47 to -50 were collected ca. 0.8 m below the base of the stratigraphically overlying San Colombano Limestone. The latter is as thick, but of more uniform facies here than at Grand Rocher (fig. 3A) and its base is dated as late Kimmeridgian, based on the presence of foraminifera Everticyclammina virguliana and “Conicospirillina basilensis” (Peybernès in Guérin, 1984). Sub-unit SC III, situated at a higher level both topographically and structurally, is well-exposed north-west of the summit situated at 820 m elevation (fig. 3A, geological section Y-Y’, fig. 3C). Pillow-lavas here are overlain by a thick radiolarite sequence, towards the top of which is intercalated a 5 m-thick massif double bed of calciturbidites (“double barre”) containing a late Oxfordian to early Kimmeridgian microfauna with Heteroporella morillonensis [Peybernès et al., 2001]. Southwards, ca. 200 m away from the previous section, the track joining the San Colombano σ summit to Novella (through Bocca a Croce) offers an accessible outcrop of that sub-unit SC III (fig. 3C, section X-X’, right part). Tectonically isolated from their basement of pillow-lavas, thick radiolarites (Samples 85C-56 to -60 of this study) are intensively folded, together with decimetric to metric intercalations of more or less silicified calcarenites. Some of these limestone beds contain abundant reworked oolites and small fragments recalling debris of the Hercynian basement. They are regarded as of Kimmeridgian age by Peybernès et al. [2001].

In its southern part, the Novella unit forms a large synformal structure folded along a N-S axis. The Cretaceous sequence here is often detached and folded above the ophiolitic pillow lavas. Rare outcrops of radiolarites, overlying stratigraphically basaltic lavas, may be found either under the San Martino (lower Cretaceous Palombini facies) or the “flysch à lydiennes” (Albian-Cenomanian) formations. An exceptional outcrop along the “km 59” of the Calvi – Ponte Leccia railroad allows observation of 7 m thick radiolarites overlying pillow lavas and hyaloclastites. They are essentially green and contain intercalations of hyaloclastites at their lower part (fig. 4, level 6), but they become reddish-violet towards the upper part (level 5). In addition to radiolaria yielded previously from the upper half (samples 85C-35 to -40, fig. 4), a new radiolarian fauna has been now identified from the lower part (sample 85C-44, fig. 4). Radiolarites are followed by ca. 5 m of a poorly exposed zone, with cherty limestones containing redeposited oolites and Trocholina (level 4), regarded as of Kimmeridgian age by Peybernès et al. [2001]. The sequence is better exposed upwards, displaying ca. 5 metres of siliceous shales and cherts, in which Lamellaptychus gr. beyrichi, a species indicative of a Kimmeridgian to early Berriasian age, is reported [Durand-Delga et al., 1978]. Reddish at their lower part, they become greenish and more shaly towards the top (2). The outcrop ends with ca. 3 m of grey-pink limestones (1) containing Middle-Upper Berriasian Calpionella elliptica and Calpionellopsis oblonga [Routhier, 1956; Parsy-Vincent, 1974; Durand-Delga, 1986].

Bull. Soc. géol. Fr., 2008, n° 3
This section at “km 59” corresponds [Principi et al., 2004] to the “Bocca di U Sorbello, along the railroad” of Conti et al. [1985]. The name of their section was taken from the small pass situated at ca. 1 km to the west of “km 59”.

RESULTS

Taxonomic concepts applied during this study follow those stated by Baumgartner et al. [1995a] and O’Dogherty et al. [2006].

San Colombano sub-unit I, NE of Grand Rocher

In addition to the assemblages reported by De Wever et al. [1987], species Cinguloturris carpatica DUMITRICA (pl. I, fig. 1) was recently identified in both samples 85C-47 and 85C-48. Its co-occurrence with Hiscocapsa robusta (MATSUOKA) (pl. I, fig. 8) allows correlation of these samples with the Unitary Association Zone (U.A.Z.) 7 (late Bathonian – early Callovian) of Baumgartner et al. [1995b]. The time interval re-evaluated by De Wever and Danelian [1995] and Bill et al. [2001], based on data of De Wever et al. [1987], is confirmed and further specified. An upper age limit (Bathonian?) is set for the last basaltic extrusions of the Ligurian oceanic crust preserved at San Colombano. Moreover, since the overlying San Colombano Limestone is dated as late Kimmeridgian at its base, a significant stratigraphic gap (middle Callovian to early Kimmeridgian) is inferred (fig. 5).

San Colombano-Novella track (sub-unit III)

The radiolarian assemblages yielded from samples of this section were re-evaluated previously as covering a poorly constrained interval of the Late Jurassic [De Wever and Danelian, 1995; Bill et al., 2001]. We have now discovered species Emiluvia pentaporata STEIGER (=E. bisellea DANELIAN; pl. I, fig. 11) in both samples 85C-56 and 85C-57, which allows correlation with the late Kimmeridgian-early Tithonian interval (U.A. Zone 11 of Baumgartner et al. [1995b]). The new, better defined radiolarian age from San Colombano-Novella track establishes that radiolarites accumulated until the late Kimmeridgian-early Tithonian. This is in agreement with redeposited Kimmeridgian foraminifera (Labyrinthina mirabilis) found by Peybernès [in Peybernès et al., 2001] in the oolitic calcarenites intercalated with radiolarites along the San Colombano-Novella track.

Section at “km 59” of the railtrack linking Calvi to Ponte Leccia (Novella unit)

An oligospecific radiolarian assemblage (Archaeodictyomitra sp. cf. A. rigida PESSAGNO, Cinguloturris carpatica DUMITRICA, Gongylothorax sakawaensis MATSUOKA, Podobursa helvetica (RÜST), Praewilliriedellum convexum (YAO) and Williriedellum sp. cf. W. yaoi (KOZUR) is now identified in a
new sample (85C-44), situated ca. 2 m above the last hyaloclastites (fig. 4, level 6). The co-occurrence of C. carpatica (pl. I, fig. 13), and G. sakawaensis (pl. I, fig. 14) allows correlation of this sample with the U.A.Z. 7 (late Bathonian – early Callovian) of Baumgartner et al. [1995b]).

Species Cinguloturris carpatica is found up to the top of radiolarites “5” (sample 85C-35, plate, fig. 15) and its co-occurrence with Stichocapsa robusta (pl. I, fig. 16-17) allows correlation of sample 85C-35 with the U.A.Z. 7 of Baumgartner et al. [1995b]. This could suggest that accumulation of the entire 7 m thick radiolarite sequence [BAL 1 of Peybernès et al., 2001] took place during the late Bathonian – early Callovian interval, further defining the previously suggested age range (U.A.Z. 5-7) [De Wever et al., 1987; De Wever and Danelian, 1995]. However, a biostratigraphic incompatibility arose during this revised study. More particularly, age assignment for sample 85C-36 (situated just below 85C-35) appears to be problematic, because species which are not supposed to co-occur in the zonation of Baumgartner et al. [1995b] are present in the same assemblage in our material. The same is true for the recent biozonation by Beccaro [2006]. Thus, species Triactoma parablakei YANG & WANG (pl. I, fig. 18), the last occurrence of which is supposed to be in U.A.Z. 7 (or zone B of Beccaro [2006]), is found together with Zhamoidellum ventricosum DUMITRICA and Z. ovum DUMITRICA (pl. I, figs. 20 and 21, respectively), first occurring at U.A.Z. 8 and 9 (or zone C and D of Beccaro [2006]), respectively. This is a common problem now, raised in numerous cases [i.e. discussion in O'Dogherty et al., 2006] and can only be solved by reprocessing the new data with those used for establishment of the above biozonations. It is worth noting that neither species of Zhamoidellum was found in the better preserved microfauna yielded from San Colombano II section, north of Grand Rocher. It is therefore possible that the top of radiolarites overlying lavas and hyaloclastites at “km 59” might be slightly younger (middle-late Oxfordian?) than a typical assemblage indicative of U.A.Z. 7. However, the presence of Palinandromeda podbielensis in sample 85C-40 (pl. I, fig. 22) sets an upper age limit, because this species is known to have last occurred in the middle-late Oxfordian (U.A.Z. 9).

DISCUSSION

New radiolarian data from radiolarites overlying ophiolitic lavas of the Balagne nappe establish a relative synchronicity (U.A.Z. 7) for the end of oceanic volcanic activity between those parts of oceanic crust preserved in the San Colombano sub-unit I and the southeastern part of Novella unit. An oligospecific radiolarian assemblage reported by Conti et al. [1985] from 5.7 m above lavas at “Bocca di U Sorbello” was recently re-evaluated by Chiari et al. [2000] as indicative of U.A.Z. 7. This outcrop is considered here as the same as our “km 59” railroad section of this study. This means that sections “28” (Bocca di U Sorbello) and “29” (Railroad) discussed recently by Principi et al. [2004] represent one and the same section. Therefore, all currently available data from the Balagne nappe point to the late Bathonian-early Callovian as the oldest age interval for radiolarite accumulation above the ophiolitic lavas. With the exception of a slightly older radiolarian age (middle Bathonian, U.A.Z. 6) in the Gets nappe of the Swiss Alps [Bill et al., 2001], and the one assigned tentatively to radiolarites from the Chenaillet-Montgenèvre ophiolite in the French-Italian Alps [Cordey and Bailly, 2007], the age established for the base of radiolarites from the Balagne nappe is amongst the oldest ages available so far from ophiolites of the Ligurian ocean and coeval (U.A.Z. 7) with the one from Val Gravuglia of Italy (eastern Liguria) [Chiari et al., 1997]. Finally, the late Bathonian-early Callovian radiolarian age obtained for the base of the sedimentary cover of the Balagne ophiolite is in good agreement with the 169±3 Ma (middle-late Bajocian, according to Pálfi et al. Bull. Soc. géol. Fr., 2008, n° 3.

FIG. 2. – A) Geological sketch map of the Balagne nappe area with position of the studied sections; B) Simplified structural section of the Balagne nappe [after Peybernès et al., 2001].

FIG. 2. – A) Schéma géologique de la région de la nappe de Balagne avec la position des coupes étudiées ; B) Coupe structurale simplifiée de la nappe de Balagne [d’après Peybernès et al., 2001].
The dramatic facies change between radiolarites and the San Colombano Limestone at subunit SC I argues for a major palaeoenvironmental change for some segments of the Balagne realm, which could be possibly due to a local uplift of the Grand Rocher oceanic floor, as suggested by Durand-Delga [1986, 1997] and Peybernès et al. [2001]. The important hiatus revealed at San Colombano sub-unit I (north-east of Grand Rocher) was possibly in part due to non deposition on a submarine swell, as carbonate production on platforms was in crisis, nannoplankton was scarce and the light radiolarian tests could have been swept away by bottom currents [Baumgartner 1990; Danelian et al., 1997; Bartolini and Cecca, 1999]. It is also possible that the hiatus is partly due to submarine erosion, since a 50 cm-deep erosional surface between the San Colombano Limestone and radiolarites can be observed for a few tens of meters northeast of the studied outcrop (fig. 3B). Accumulation of the San Colombano Limestone and its platform carbonate counterparts in Corsica was probably the result of a gradual recovery of carbonate production on platforms during the Kimmeridgian [Weissert and Mohr, 1996] and of a generalized upper Kimmeridgian platform progradation, such as in the Friuli-Umbria-Marche system [Colaccichi and Bigozzi, 1995].

The Kimmeridgian distribution of sedimentary facies in the various units of the Balagne nappe argues for the presence of a palaeoslope, as previously suggested by Durand-Delga et
PLATE I. – Radiolarian assemblages recovered from samples of Balagne nappe. 1-10) San Colombano, NE of Grand Rocher, Sample 85C-47; 11-12) San Colombano-Novella track, Sample 85C-57; 13-22) Railtrack “km 59”; 13-14) Sample 85C-44; 15-17) Sample 85C-35; 18-21) Sample 85C-36; 22) Sample 85C-40. Scale equals to 100 µm for all specimens.

PLANCHE 1. – Assemblages de radiolaires extraits des échantillons étudiés de la nappe de Balagne. 1-10) San Colombano, NE du Grand Rocher, éch. 85C-47; 11-12) route San Colombano-Novella, éch. 85C-57; 13-22) voie ferrée au “km 59”; 13-14) éch. 85C-44; 15-17) éch. 85C-35; 18-21) éch. 85C-36; 22) éch. 85C-40. La barre est égale à 100 µm pour tous les spécimens.


Bull. Soc. géol. Fr., 2008, n° 3
al. [1997] and Peybernès et al. [2001]. While the San Colombano neritic limestones were deposited at the upper part of a slope, close to a Late Jurassic carbonate platform known from many autochthonous and parautochthonous units of Corsica [Durand-Delga, 1986], the radiolarites of San Colombano-Novella track sections accumulated at deeper environments, where carbonate platform influence was only occasional. The presence of fragments of the Hercynian basement in the calcarenites intercalated with the upper Kimmeridgian-lower Tithonian radiolarites of the San Colombano-Novella track section establish that the erosion of the Hercynian basement situated near the Balano-Ligurian palaeoslope had begun in the late Kimmeridgian.

CONCLUSIONS

The new and revised radiolarian ages from the Balagne nappe provide relatively accurate constraints for the end of volcanic activity on the Ligurian oceanic crust preserved in Corsica. Radiolarites started to accumulate during all or part of the late Bathonian to early Callovian interval in both San Colombano and Novella oceanic realms. This is amongst the oldest ages available so far from the sedimentary cover of ophiolites of the Ligurian ocean. An important stratigraphic gap is documented between radiolarites and overlying shallow water carbonates of the San Colombano Limestone. An uplift of the oceanic floor preserved at San Colombano is envisaged as previously suggested by Durand Delga et al. [1997]. This would generate the formation of a slope between the San Colombano and Novella units. A Callovian-Oxfordian platform carbonate production crisis, combined with significant bottom current action and submarine erosion, may explain the hiatus at San Colombano. It is possible that a similar gap also exists at section “km 59” of the Novella unit between the top of radiolarites and overlying redeposited oolithic calciturbidites, although there is no conclusive evidence. Radiolarite accumulation continued in the distal part of the Balagne margin until the late Kimmeridgian-early Tithonian, when sedimentation switched to Maiolica-type carbonates as in many Tethyan basins.

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