Dating the Tethyan Ocean in the Western Alps with radiolarite pebbles from synorogenic Oligocene molasse basins (southeast France)

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Running title: Radiolarite pebbles from Alpine Oligocene molasses

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Abstract

For the first time in the Western Alps, radiolarite pebbles collected from Tertiary foreland molasse conglomerates are treated for microfossil extraction and dated. Among fourty pebbles selected in the field, seven of them released diagnostic radiolarian assemblages ranging in age from Late Bajocian-Early Callovian to Middle Oxfordian-Early Tithonian. These ages overlap previous biochronological data obtained from *in situ* localities of the Schistes Lustrés Piemont zone of the French-Italian Alps and triple the number of diagnostic radiolarite samples known so far in this segment of the chain. The diagnostic pebbles are characterized by low grade metamorphism, showing that some eroded thrust-sheets from the oldest parts of the ocean escaped any tectonic burial during the Alpine convergence. Mixing of low and high-grade radiolarites, mafics and ultramafics pebbles implies that a variety of ocean-derived units was exposed. This tectonic scenario involves tight refolding and severe uplift of the Eocene subduction wedge in the Early Oligocene.

1. Introduction

The European Alps straddle the plate boundary between Europe and Africa where divergence dominated during most of Jurassic-Cretaceous times followed by convergence from the Late Cretaceous onwards (e.g. Tricart 1984). As a major witness to plate divergence, ophiolites derive from a small Tethyan ocean basin, the Alpine Tethys also named Liguria, Liguria-Piemont or Piemont-Liguria (review in Bernoulli and Jenkyns 2009, Lagabrielle 2009, Manatschal and Müntener 2009, de Graciansky et al. 2010). In the Western Alps, dismembered ophiolites and associated deep-sea sediments compose most of the Piemont zone (review in Schmid et al. 2004). They display subduction-related HP-LT metamorphic imprint evolving from blueschist facies in the outer Piemont units to eclogite facies in the inner ones (review in Bousquet et al. 2008). As an exception, the Chenaillet ophiolite (Fig. 1) escaped this metamorphism, suggesting that it derived from an obducted slab of oceanic lithosphere (Mével et al. 1978, Barfety et al. 1995 with references therein).

Reconstructing the paleogeography of this vanished ocean at successive steps from opening to closure remains a major challenge among Alpine geologists. Two difficulties remained for a long time: the rarity of radiometric ages from ophiolites and the missing fossil record due to metamorphism and/or erosion of sedimentary covers. Fortunately, some of the Western Alps units closely resemble the unmetamorphic ophiolite thrust sheets of the Northern Apennines which suggest that Tethyan ocean spreading occurred during the Middle-Late Jurassic and possibly the Early Cretaceous (e.g. Lemoine et al. 1970, de Graciansky et al. 2010). Most modern reconstructions for the Western Alpine ocean derive from Marcel Lemoine's sketches of the early 1980's. They show the Alpine Tethys and the Central Atlantic as twin oceans for their initial opening and spreading (e.g. Lemoine 1983). On the Tethyan European paleomargin, the transgressive units and their fossil record exposed in the Briançonnais domain document the breakup unconformity (Lemoine et al. 1986) and provide a Middle Jurassic age (Late Bathonian) for the timing of initial opening of the nearby ocean (Lemoine et al. 2000, Bill et al. 2001).

A significant improvement came with the successive discovery and dating of three radiolarite supraophiolitic localities: (1) the Cascavelier Peak near Saint-Véran in Southern Queyras (De Wever and Caby 1981, De Wever and Baumgartner 1995), (2) the Traversiera massif near the French-Italian border in the upper Ubaye valley (Schaaf et al. 1985, De Wever et al. 1987, De Wever et Baumgartner 1995), and (3) more recently the Rocher de la Perdrix in the Montgenèvre massif, located structurally below the Chenaillet ophiolite *s.s.* (Cordey and Bailly 2007). In these three sites (Fig. 1), radiolarian faunas are preserved in low-temperature blueschist-bearing metacherts at the front of the Piemont "Schistes lustrés" complex (Gidon et al. 1994; Tricart et al. 2003). These three fossil localities directly argue for an ocean opening during a period straddling the Middle and Late Jurassic times (Cordey and Bailly 2007).

In order to improve our knowledge of the Alpine ocean history, we explored the potential of synorogenic conglomerates derived from the erosion of oceanic thrust sheets building the Alpine wedge. Rüst (1885) was the first to describe Jurassic radiolarians from chert pebbles of western Switzerland molasses, but microfossil chemical extractions were not yet applied at the time. A more recent interest for syn- or postorogenic clastics was developed in the North American Cordillera on the well-known "chert pebble conglomerates" associated with Mesozoic ocean sutures and accreted terranes (Seiders and Blome 1984; Cordey 1992a, 1992b, 1998). In this Alpine study, our objectives were not only to find new dates related to the Jurassic opening of Tethys but also to document ocean closure and subsequent mountain building during Early Oligocene time.

2. The Oligocene polygenic conglomerates in the foreland of the southern Western Alps

Within the Paleogene molasses of the Western Alps external zone, our investigation focused on the French Subalpine chains located to the south of the Pelvoux massif (Ford et al. 1999, Ford and Lickorish 2004). In this region, Early Oligocene intra-orogenic basins (Fig. 2) contain conglomerates known for their ocean-derived pebbles (Termier 1895 in Gubler 1958, Boussac 1912) such as fragments of mafics and ultramafics rocks as well as radiolarian chert (Ferry et al. 2005). In the field, these radiolarite pebbles are easily recognizable by their dark red colour (Fig. 3). They represent the “exotic” pebbles *par excellence*, occupying a privileged position in the Alpine literature as symbols of a “Penninic” signature, the Swiss term to describe the internal Alpine zones. The Early Oligocene molasses are preserved within small basins in the foreland of the Paleogene Alpine accretionary wedge (e.g. Sissingh 2001) and were fed by clastic sediments derived from the erosion of uplifting Briançonnais and Piemont zones (Morag et al. 2008; Bernet and Tricart 2011). Initially, our main target was the Barrême basin, a small and well-studied valley located to the east of Digne thrust (de Graciansky 1972, Artoni and Meckel 1998, Evans and Elliott 1999). A second site was found farther north in the “Petit Buëch” valley near Montmaur (Fig. 1) where tectonically pinched molasses named “Nagelfluh” correspond to the southward extension of the Devoluy basin (Gidon 1971, Meckel et al. 1996).

3. Biostratigraphic results: faunal assemblages and ages

Seven diagnostic chert pebbles were found in a series of fourty selected in the field. Each pebble was processed individually using standard chert-etching techniques with hydrofluoric acid. Pebble 7064-E1 was collected at “La Poste de Clumanc” conglomerates (Fig. 2) near the northern end of the Barrême basin (e.g. Chauveau and Lemoine 1961). Six pebbles numbered 7057-3 to 7057-22 were sampled in the “Petit Buëch” valley (Gidon 1971).

Pebbles faunal contents and ages are presented in Table 1. Key radiolarian taxa are illustrated in Fig. 4. We use the standard Tethyan radiolarian zonation of Baumgartner et al. (1995) based on Unitary Associations (UAZ) as well as complementary data from O'Dogherty et al. (2006). The "age of a pebble" refers here to the age of the source radiolarite bed, not the age of formation or deposition of the pebble.

Biochronology and ages are based on the following radiolarian occurrences:

- 7057-3: the assemblage contains *Archeospongoprunum* cf. *imlayi* Pessagno, *Orbiculiformella* sp., *Stichocapsa robusta* Matsuoka, and *Stichocapsa* sp.. The age is provided by the occurrence of *S. robusta* Matsuoka known from UAZ 5 to UAZ 7 corresponding to the Late Bajocian-Early Callovian interval.
- 7057-8 comprises *Cinguloturris carpatica* Dumitrica, *Praeconocaryomma* sp., *Stichocapsa* aff. *robusta* Matsuoka (Fig. 4, n° 18) and ?*Stichomitra* sp. (Fig. 4, n° 14). This assemblage is assigned to biozones UAZ 7-11 of Late Bathonian-Early Callovian to Late Kimmeridgian-Early Tithonian age.
- 7057-14 contains *Acaeniotyle diaphorogona* Foreman (Fig. 4, n° 26), *Archeodictyomitra apiarum* (Rüst), *Archeodictyomitra* sp. (Fig. 4, n° 7), *Cinguloturris carpatica* Dumitrica (Fig. 4, n° 4), *Emiluvia ordinaria* Ozvoldova, *Mirifusus* sp. (Fig. 4, n° 3), *Parahsuum carpathicum* Widz & De Wever (Fig. 4, n° 11), ?*Parvicingula mashitaensis* Mizutani (Fig. 4, n° 10), *Podobursa* cf. *spinosa* Ozvoldova (Fig. 4, n° 24), *Protunuma* sp. (Fig. 4, n° 13), *Pseudoeucyrtis* sp. (Fig. 4, n° 1), *Zhamoidellum ovum* Dumitrica (Fig. 4, n° 17) and *Zhamoidellum* sp. (Fig. 4, n° 19). This assemblage is attributed to biozones UAZ 9-11 of Middle Oxfordian to Early Tithonian age.
- 7057-15 contains a peculiar association which is not reported in Baumgartner et al. (1995) biozonation but is documented by O'Dogherty et al. (2006): *Yaocapsa* sp. (Fig. 4, n° 12),

Cinguloturris carpatica Dumitrica, *Zhamoidellum* cf. *argandi* O'Dogherty, Gorican & Dumitrica (Fig. 4, n° 16) and *Zhamoidellum* cf. *calamin* O'Dogherty, Gorican & Dumitrica (Fig. 4, n° 22). This assemblage is tentatively assigned to UAZ 6-7 (O'Dogherty et al. 2006).

- 7057-20 contains *Archeodictyomitra apiarum* (Rüst), *Bernoullius* cf. *dicera* Baumgartner (Fig. 4, n° 29), *Praeconocaryomma* sp. and *Stichocapsa* sp.. It provides a Middle Callovian-Early Kimmeridgian age (UAZ 8-10). As the occurrence of species *B. dicera* Baumgartner is uncertain, the upper age limit of this association is tentative.

- 7057-22: correlation to biozone UAZ 7 of Late Bathonian-Early Callovian age is provided by co-occurrence of *Cinguloturris carpatica* Dumitrica (Fig. 4, n° 4) and *Pseudoristola tsunoensis* (Aita) (Fig. 4, n° 22). Other radiolarians compatible with this age determination are *Williriedellum* sp. 1 (Fig. 4, n° 23) only documented in Les Gets nappe along with morphotypes from UAZ 6 and 7 (O'Dogherty et al. 2006) and *Archeospongoprunum elegans* Wu (Fig. 4, n° 2) also known in this time interval. Other morphotypes present in 7057-14 are *Arcanicapsa* cf. *leiostraca* (Foreman) (Fig. 4, n° 21), *Archeodictyomitra* sp. (Fig. 4, n° 8), *Cinguloturris* sp. (Fig. 4, n° 5), *Emiluvia* cf. *chica* Foreman (Fig. 4, n° 27), ?*Fultocapsa* sp. (Fig. 4, n° 25), *Homoeoparonaella argolidensis* Baumgartner (Fig. 4, n° 28), *Mirifusus* sp., *Pseudodictyomitrella* cf. *tuscanica* Chiari, Cortese & Marcucci (Fig. 4, n° 15), and *Tritrabs rhododactylus* Baumgartner (Fig. 4, n° 30).

- 7064-E1 contains *Archeodictyomitra apiarum* (Aita) (Fig. 4, n° 4), *Archeospongoprunum* cf. *imlayi* Pessagno (Fig. 4, n° 3) and *Cinguloturris carpatica* Dumitrica (Fig. 4, n° 4). This assemblage is assigned to UAZ 8-11 of Middle Callovian to Early Tithonian age.

In summary:

1. Our chert pebbles range in age from Late Bajocian-Early Callovian (UAZ 5-7) to Middle Oxfordian-Early Tithonian (UAZ 8-11).

2. The oldest pebble could be as old as Late Bajocian (base of UAZ 5) but also as young as Early Callovian (top of UAZ 7).

3. The youngest pebble could be as old as Middle Oxfordian (7057-14) and as young as Early Tithonian (7057-14 or 7064-E1).

4. Three pebbles are Middle Jurassic in age. Among them, 7057-22 is restricted to UAZ 7 of Late Bathonian-Early Callovian age. The two others 7057-3 and -15 are possibly of the same age but could also be younger (UAZ 5-7 and UAZ 6-7 respectively).

5. Only one pebble (7057-14) is with certainty Late Jurassic in age. The three remaining pebbles are either Middle or Late Jurassic (7057-8, 7057-20, and 7064-E1).

4. Comparisons with previous radiolarian localities of the Piemont Schistes Lustrés zone

4.1. Biochronology

As mentioned previously, only three localities of supraophiolitic radiolarites are dated so far in the Schistes Lustrés complex of the French-Italian Alps. They range in age from Middle Bathonian to Middle-Late Oxfordian:

1. the Cascavelier Peak radiolarite near Saint-Véran was originally dated as Late Oxfordian-Middle Kimmeridgian (De Wever and Caby 1981). This age was later revised to the Middle or Late Oxfordian (UAZ 9) (De Wever and Baumgartner 1995).

2. the Traversiera massif locality was originally found by R. Polino (Torino), with radiolarians occurring in phosphate nodules at the base of the sedimentary cover of the ophiolite (Y. Lagabrielle, pers. com. 2006). It was dated as Late Oxfordian-Early

Kimmeridgian (Schaaf et al. 1985), an age later revised as Late Bathonian-Early Callovian (UAZ 7) (De Wever et al. 1987; De Wever et Baumgartner 1995).

3. the “Rocher de la Perdrix” radiolarites from the Chenaillet massif near Montgenèvre are exposed in the Lago Nero-Replatte thrust sheet located structurally beneath the Chenaillet ophiolite thrust sheet *s.s.*. It was tentatively assigned to UAZ 6 of Middle Bathonian age. It could be the oldest radiolarite exposure of the Piemont zone (Cordey and Bailly 2007).

In comparing our results with these biochronological data, we find that the ages of radiolarite pebbles overlap almost entirely the age range known from *in situ* Piemont Schistes Lustrés radiolarite localities. Our results also lead to the following observations:

1. In our sampling, biozone UAZ 7 seems well represented in 2 pebbles, possibly 4. It matches the age established in the Traversiera massif (Late Bathonian-Early Callovian).

2. The occurrence of biozone UAZ 6 known at the Chenaillet is not confirmed but could be present in 2 of the 7 pebbles.

3. Our youngest pebble could be coeval to the Pic Cascavelier locality of Middle-Late Oxfordian age (UAZ 9) but could also be younger (Kimmeridgian or Early Tithonian).

4.2. Faunal content

Some radiolarian morphotypes present in our pebbles were not reported before in the Piemont Schistes Lustrés *in situ* radiolarites. The Pic Cascavelier locality (UAZ 7) has an assemblage of sixteen species in which only *Homoeoparonaella argolidensis* Baumgartner occurs in one pebble (7057-22). The St-Véran section (UAZ 9) comprises nineteen species in which only *Acaeniotyle diaphorogona* Foreman and potentially *Bernoullius dicera* (Baumgartner) are present in our assemblages. Finally, the Rocher de la Perdrix locality has only 5 morphotypes with 2 species of the genus *Kilinora* which does not occur elsewhere. Overall, our pebbles seem richer in nassellarians, including morphotypes of *Cinguloturris*, *Fultocapsa*, *Protunuma*, *Pseudodictyomitrella*, *Pseudoristola*, *Pseudoeucyrtis*, *Stichocapsa*, *Yaocapsa* and *Zhamoidellum* which were not reported in other localities of the Piemont Schistes Lustrés zone (Bill et al. 2001). On one hand, these discrepancies may not be paleontologically significant as they could result from taphonomical biases. On the other hand, they could suggest that radiolarite beds stored as pebbles in molasse conglomerates have no *in situ* equivalents, or that these equivalents have been entirely destroyed or metamorphosed. We have presently no argument for preferring one of these hypotheses.

5. Discussion and conclusions

5.1. The Alpine Tethys birth and spreading scenario

The oldest radiolarite sample documented in our study is Late Bajocian or Early Callovian in age. If we considers that *in situ* radiolarites of the Western Alps are associated with ophiolite basements, this age remains compatible with the classical scenario of synchronous opening for both the Central Atlantic and the Alpine Tethys in the Middle Jurassic (Lemoine et al. 2000, Bill et al. 2001, Cordey and Bailly 2007, de Graciansky et al. 2010). However we do not know if the sampled molasses contain older oceanic remnants. In the outer Piemont zone, the three thrust-sheets bearing diagnostic supraophiolitic radiolarites are imbricated with thrust-sheets derived from the European distal margin (Caby et al. 1971, Tricart et al. 2003). The simplest hypothesis is that our pebbles result from the erosion of ophiolite-bearing thrust-sheets of a similar Piemont paleogeographic origin, i.e. the part of the ocean located at the foot of the European margin. However, one cannot rules out a source in one or several now entirely eroded units that originated from the other side of the ocean at the foot of the African margin (Adria).

With the contribution of these fossiliferous pebbles, the number of radiolarites dated so far in the Piemont zone of the Western Alps increases from 3 to 10. If the occurrence of Kimmeridgian or Tithonian cherts was confirmed by future sampling, it would extend the time span represented in these deep-sea sediments from 16 to 20 Myr. For an ocean with a very low spreading rate of ~2 cm/year as expected for the Alpine Tethys (Lagabrielle and Cannat 1990, Lagabrielle and Lemoine 1997, Lagabrielle 2009, Manatschal and Müntener 2009), this time span could correspond to 400 km in width. Of course this estimate is to be considered with caution, as pebbles could come from any level of an original radiolarite succession resting on a slightly older crust.

We do not bring any evidence for the occurrence of radiolarite sedimentation in the Early Cretaceous and consequently an even wider oceanic domain. However most Tethyan basin facies grade into pelagic limestones or shale/limestone alternation in the Late Tithonian (Bill et al. 2001). All direct and indirect fossiliferous elements of the ocean found in ophiolite covers and molasses are from the oldest parts of this domain, corresponding to remnants of the so-called “narrow ocean” stage. As already observed elsewhere in the Alpine-Apennine domain, radiolarite units are Middle and Late Jurassic without any evidence of Cretaceous chert sedimentation (Bill et al. 2001). Apart from the Balma and Chiavenna units in the Valais oceanic domain (93 Ma U/Pb ages; Liati and Froitzheim 2006), all other radiometric ages overlap the age of radiolarian cherts (Manatschal and Müntener 2009). In the hypothesis of ongoing Cretaceous rifting, elements of a younger and more axial part of this ocean remain to be identified. If such elements are no longer exposed, they could remain hidden at depth. They could also can have been eroded after exhumation. If this is the case, further investigation on foreland detrital formations is needed. However, the most probable explanation is that during the Cretaceous, the Alpine Tethyan ocean was no more active and the oceanic spreading was mostly accommodated in the Central Atlantic to the west and the Neotethys to the east.

5.2. The Alpine orogenic wedge building scenario

During Early Oligocene times, the present-day Alpine internal zones inherited part of the Eocene subduction-related accretionary wedge that had just undergone syncollisional polyphase shortening (Tricart et al. 2006, Morag et al. 2008, Bernet and Tricart 2011). The erosion of the new-born mountain range with exposed margin- and ocean-derived thrust sheets fed rather abruptly the foreland molasses which show a great variety of lithologies, not only radiolarites but also magmatic pebbles such as basalts and gabbros with greenschist to blueschist facies, as well as serpentinized peridotites with blueschist to eclogite facies (de Gracianski et al. 1971, Schwartz et al., in press). As this foreland was progressively affected by folding and forethrusting, Oligocene molasse basins born along the Alpine front evolved as transported basins before being closed and incorporated to the Alpine wedge (present-day external zone : see review in Ford et al. 2006).

Although *in situ* fossiliferous radiolarian cherts of the outer Piemont zone underwent high greenschist or blueschist facies metamorphism, our study shows that some eroded radiolarite units buried as molasse pebbles experienced low P-T conditions. This is supported by the following observations: 1/ low silica recrystallization of pebbles’s radiolarite matrices, 2/ absence of phengites in the pebbles microfacies; these white micas are commonly observed in the HP blueschist siliceous facies of the Piemont zone, 3/ fair preservation of radiolarian microfossils. It is also noteworthy that Mesozoic radiolarite pebbles of the Subalpine molasse display much higher rates of microfossil recovery than *in situ* Mesozoic radiolarites of the Piemont zone. Interestingly, the same low-grade metamorphism characterizes the chert pebbles extracted from synorogenic conglomerates derived from the Mesozoic accretionary complexes of western North America (Seiders and Blome 1984; Cordey, 1992a, b, Cordey 1998). There, some radiolarite pebbles have revealed the existence of ocean units whose equivalent correlatives have never never found *in situ* (Cordey 1998). Our study suggests that it is also the case in the Alps.

The occurrence of low-grade radiolarite pebbles indicate that some eroded thrust-sheets originating from the oldest parts of the ocean escaped any serious tectonic burial during the Alpine convergence (Fig. 5). The 20 Myr potential age range represented by our radiolarite pebbles does not favor a single source. However, we do not know if these radiolarites derived from the European side or from both sides of the ocean spreading-ridge. Yet they show that by 30 Ma, the Alpine wedge had probably sampled the entire oceanic sediments accreted at very contrasted structural levels in the accretionary wedge. The question whether there is a link between the paleogeographic European or African origin of these remnants and their structural history remains open. Future models for the building of the Alpine wedge during early convergence will have to test the processes of a selective tectonic sampling of these paleogeographic realms during accretion.

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Table and figures captions

Table 1. Radiolarian contents of pebbles, biozones (UAZ) and ages (Baumgartner et al. 1995, O'Dogherty et al. 2006). When available, UAZ range of each taxon is provided.

Fig. 1. Location map of southern French-Italian Alps (modified from Schmid et al. 2004). Location of sampled molasse conglomerates: M, Montmaur, B, Barrême. Known sites with *in-situ* bedrock fossiliferous radiolarites: P, Rocher de la Perdrix (Chenaillet Massif), C, Cascavelier Peak (southern Queyras), T, Traversiera Massif. In red: major fault zones.

Fig. 2. Schematic stratigraphy of the Tertiary foreland series exposed in the French Subalpine zones, more specifically the Barrême basin. Barton. = Bartonian, Priabon. = Priabonian, Aquitan. = Aquitanian, conglo. = conglomerate; biostr. = biostrome. The origin of Barrême basin pebbles are the Clumanc conglomerates.

Fig. 3. Outcrop of "Nagelfluh" molasse conglomerate near the village of Montmaur; circles: pebbles of red radiolarites.

Fig. 4. Middle and Late Jurassic radiolarians from Oligocene molasses chert pebbles (Scanning Electron Microscope). For each microfossil: taxon, sample number, FC database picture number, length of scale bar.

1- *Pseudoeucyrtis* sp., 7057-14, n° 10, 260 μm.

2- *Archeospongoprunum elegans* Wu, 7057-22, n° 13, 150 μm.

3- *Archeospongoprunum* sp., 7057-E1, n° 2, 250 μm.

4- *Cinguloturris carpatica* Dumitrica, 7057-14, n° 11, 200 μm.

5- *Cinguloturris* sp., 7057-22, n° 6, 130 µm.

6- *Archeodictyomitra apiarum* (Rüst), 7057-14, n° 26, 200 µm.

7- *Archeodictyomitra* sp., 7057-14, n° 28, 150 µm.

8- *Archeodictyomitra* sp., 7057-22, n° 20, 125 µm.

9- *Archeodictyomitra* sp., 7057-14, n° 14, 150 µm.

10- ?*Parvicingula mashitaensis* Mizutani, 7057-14, n° 4, 230 µm.

11- *Parahsuum carpathicum* Widz and De Wever, 7057-14, n° 15, 150 µm.

12- *Yaocapsa* sp., 7057-15, n° 4, 160 µm.

13- *Protunuma* sp., 7057-14, n° 22, 140 µm.

14- *?Stichomitra* sp., 7057-08, n° 14, 150 µm.

15- *Pseudodictyomitrella* cf. *tuscanica* Chiari, Cortese and Marcucci, 7057-22, n° 12, 100 µm.

16- *Zhamoidellum* cf. *argandi* O'Dogherty, Gorican and Dumitrica, 7057-15, n° 16, 130 µm.

17- *Zhamoidellum ovum* Dumitrica, 7057-14, n° 19, 160 µm.

18- *Stichocapsa* aff. *robusta*, 7057-08, n° 6, 150 µm.

19- *Zhamoidellum* sp., 7057-14, n° 27, 185 µm.

20- *Pseudoristola tsunoensis* (Aita), 7057-22, n° 22, 110 µm.

21- *Arcanicapsa* cf. *leiostraca* (Foreman), 7057-22, n° 3, 140 µm.

22- *Zhamoidellum* cf. *calamin* O'Dogherty, Gorican and Dumitrica, 7057-15, n° 7, 120 µm.

23- *Williriedellum* sp. 1 (O'Dogherty et al. 2006), 7057-22, n° 9, 150 µm.

24- *Podobursa* cf. *spinosa* Ozvoldova, 7057-14, n° 5, 200 µm.

25- ?*Fultocapsa* sp., 7057-22, n° 23, 130 µm.

26- *Acaeniotyle diaphorogona* Foreman, 7057-14, n° 1, 200 µm.

27-*Emiluvia* cf. *chica* Foreman, 7057-22, n° 15, 200 µm.

28- *Homoeoparonaella argolidensis* Baumgartner, 7057-22, n° 1, 200 µm.

29- *Bernoullius* cf. *dicera* (Baumgartner), 7057-20, n° 6, 150 µm.

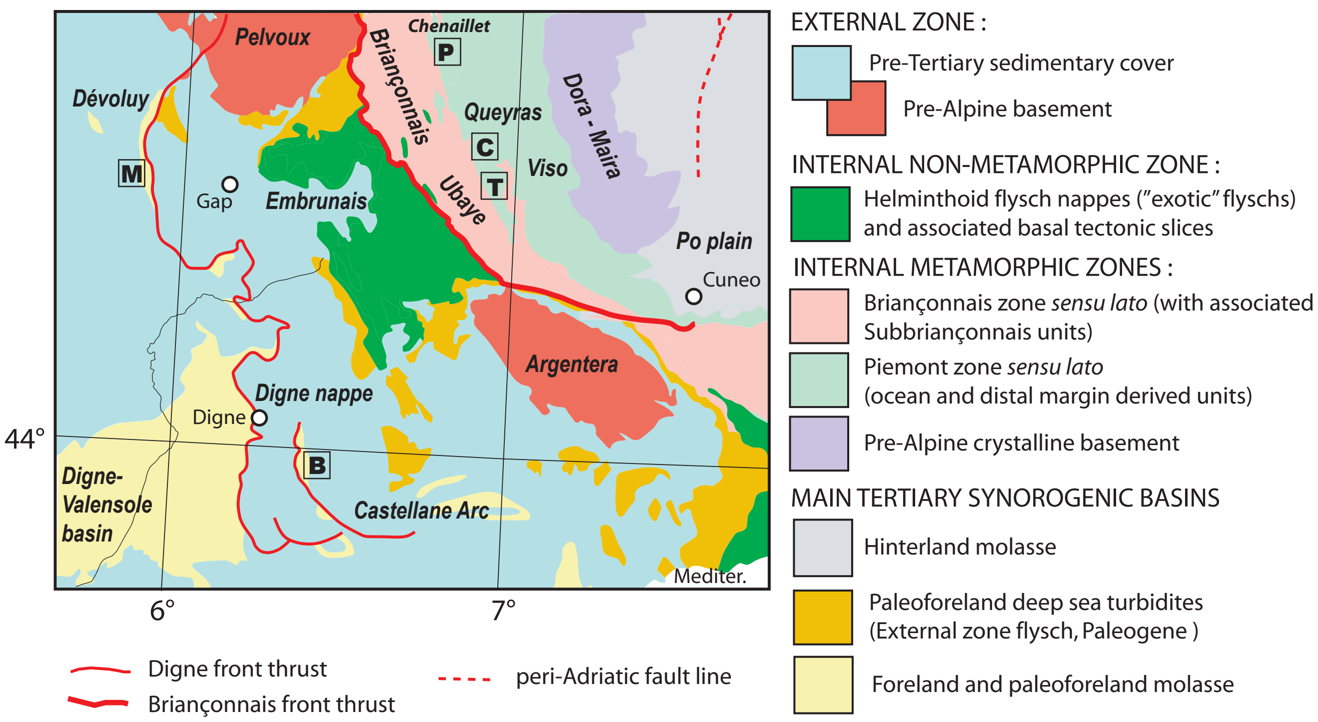
30- *Tritrabs rhododactylus* Baumgartner, 7057-22, n° 18, 200 µm.

31- *Mirifusus* sp., 7057-14, n° 3, 250 µm.

Fig. 5. Crustal cross-section model proposing an evolution for the southern Western Alps during the Early Oligocene. At that time, the Piemont thrust sheets already stacked in the upper Cretaceous-Paleocene subduction accretionary wedge underwent severe syncollision shortening. It resulted in a major orogenesis so that erosion fed abruptly the peripheral molasses in margin-derived and ocean-derived clasts whose metamorphic signatures range from non or very low-grade to high-grade blueschist facies (Lz: lizardite; Atg: antigorite).

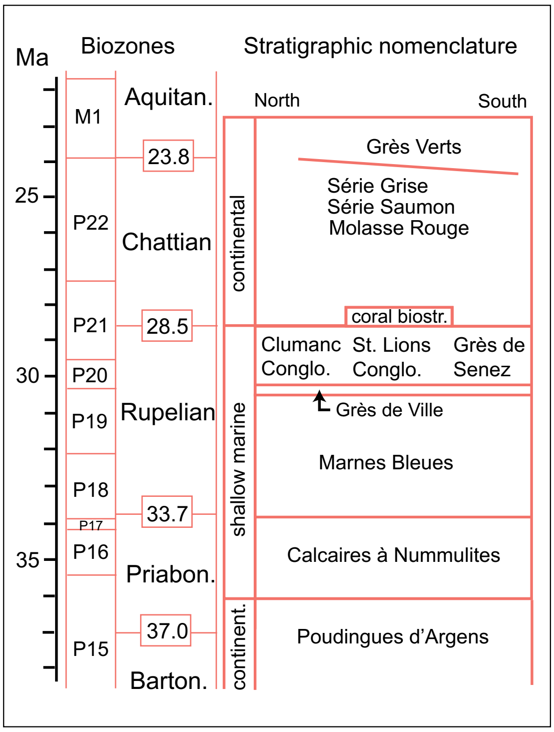
Radiolarian taxa	Radiolarite pebbles						
	7057-3	7057-15	7057-22	7057-8	7057-20	7064-E1	7057-14
Acaeniotyle diaphorogona Foreman 4-22							X
Arcanicapsa cf. *leiostraca* (Foreman)			X				
Archeodictyomitra apiarum (Rüst) 8-22					X	X	X
Archeodictyomitra sp.			X				X
Archeospongoprunum elegans Wu 6-?			X				
Archeospongoprunum cf. *imlayi* Pessagno	X					X	
Bernoullius cf. *dicera* (Baumgartner) 3-10					X		
Cinguloturris carpatica Dumitrica 7-11		X	X	X		X	X
Cinguloturris sp.			X				
Emiluvia ordinaria Ozvoldova 9-11							X
Emiluvia cf. *chica* Foreman 3-18			X				
?*Fultocapsa* sp.			X				
Homoeoparonaella argolidensis Baumgartner 4-11			X				
Mirifusus sp.			X				X
Orbiculiformella sp.	X						
Parahsuum carpathicum Widz & De Wever 7-11							X
?*Parvicingula mashitaensis* Mizutani 8-15							X
Podobursa cf. *spinosa* Ozvoldova 8-13							X
Praeconocaryomma sp.				X	X		
Protunuma sp.							X
Pseudodictyomitrella cf. *tuscanica* Chiari, Cortese & Marcucci			X				
Pseudoristola tsunoensis (Aita) 6-7			X				
Pseudoeucyrtis sp.							X
Stichocapsa robusta Matsuoka 5-7	X						
Stichocapsa aff. *robusta* Matsuoka				X			
Stichocapsa sp.	X				X		
?*Stichomitra* sp.				X			
Tritrabs rhododactylus Baumgartner 3-13			X				
Williriedellum sp. 1 (O'Dogherty et al. 2006)			X				
Yaocapsa sp. 5-6		X					
Zhamoidellum ovum Dumitrica 9-11							X
Zham. cf. *argandi* O'Dogherty, Gorican & Dumitrica 6-7		X					
Zham. cf. *calamin* O'Dogherty, Gorican & Dumitrica		X					
Zhamoidellum sp.							X
Unitary Association Zones UAZ	**5-7**	**6-7**	**7**	**7-11**	**8-?10**	**8-11**	**9-11**
Age ranges	Late Baj. or Early Bath. to Early Call.	Mid. Bath. to Early Call.	Late Bath. to Early Call.	Late Bath. or Early Call. to Late Kim. or Early Tith.	Mid Call. to ? Early Kim.	Mid Call. to Late Kim. or Early Tith.	Mid Oxf. to Late Kim. or Early Tith.

Table 1



Pelvoux
Chenaillet
P
Briançonnais
Dévoluy
Queyras
C
Dora - Maira
M
Viso
Gap
Embrunais
T
Ubaye
Po plain
Cuneo
Argentera
Digne nappe
Digne
44°
B
Digne-
Valensole
basin
Castellane Arc
Mediter.
6°
7°
Digne front thrust
Briançonnais front thrust
peri-Adriatic fault line
EXTERNAL ZONE :
Pre-Tertiary sedimentary cover
Pre-Alpine basement
INTERNAL NON-METAMORPHIC ZONE :
Helminthoid flysch nappes ("exotic" flyschs)
and associated basal tectonic slices
INTERNAL METAMORPHIC ZONES :
Briançonnais zone *sensu lato* (with associated
Subbriançonnais units)
Piemont zone *sensu lato*
(ocean and distal margin derived units)
Pre-Alpine crystalline basement
MAIN TERTIARY SYNOROGENIC BASINS
Hinterland molasse
Paleoforeland deep sea turbidites
(External zone flysch, Paleogene)
Foreland and paleoforeland molasse

Fig. 1



Ma
Biozones
Stratigraphic nomenclature
25
30
35
M1
P22
P21
P20
P19
P18
P17
P16
P15
Aquitan.
23.8
Chattian
28.5
Rupelian
33.7
Priabon.
37.0
Barton.
North
South
continental
shallow marine
continent.
Grès Verts
Série Grise
Série Saumon
Molasse Rouge
coral biostr.
Clumanc Conglo.
St. Lions Conglo.
Grès de Senez
Grès de Ville
Marnes Bleues
Calcaires à Nummulites
Poudingues d'Argens

Fig. 2

Fig. 3

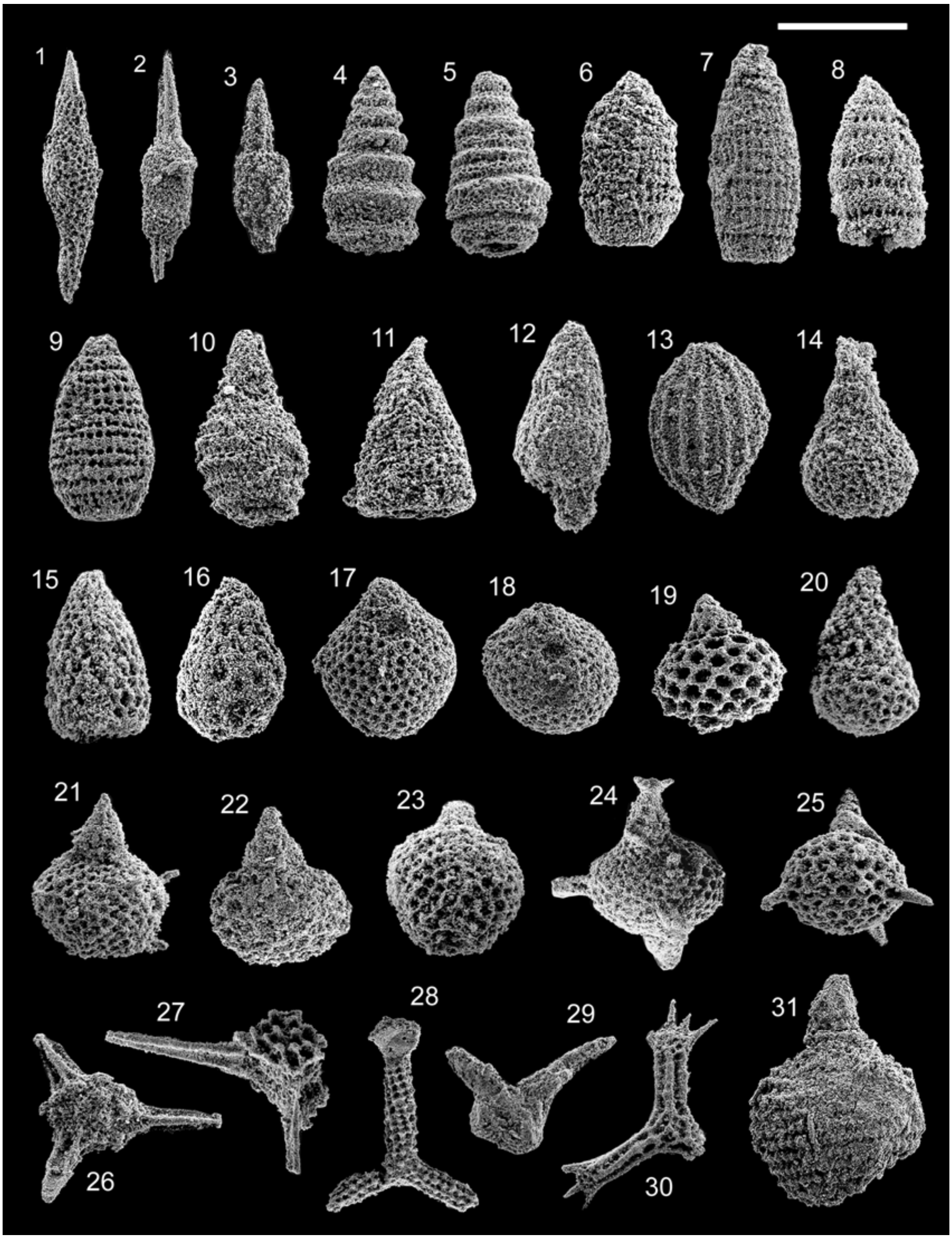

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Fig. 4

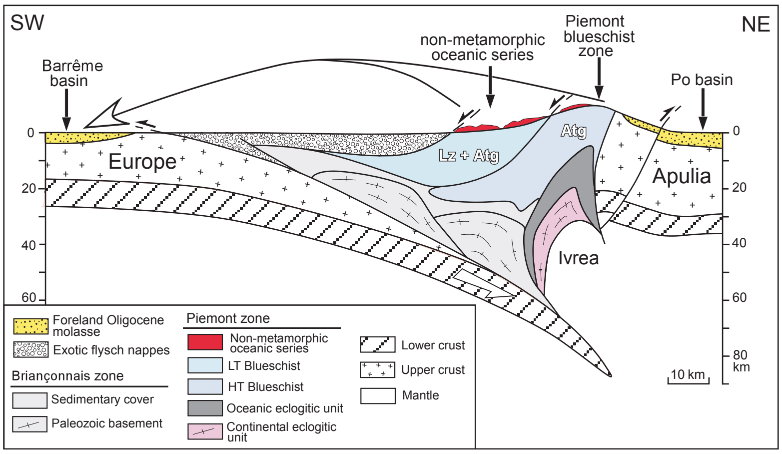
SW
NE
Barrême basin
non-metamorphic oceanic series
Piemont blueschist zone
Po basin
Europe
Lz + Atg
Atg
Apulia
Ivrea
0
20
40
60
80 km
10 km
Foreland Oligocene molasse
Exotic flysch nappes
Briançonnais zone
Sedimentary cover
Paleozoic basement
Piemont zone
Non-metamorphic oceanic series
LT Blueschist
HT Blueschist
Oceanic eclogitic unit
Continental eclogitic unit
Lower crust
Upper crust
Mantle

Fig. 5