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Fabrice Cordey, Pierre Tricart, Stéphane Guillot, Stéphane Schwartz. Dating the Tethyan Ocean in the Western Alps with radiolarite pebbles from synorogenic Oligocene molasse basins (southeast France). Swiss Journal of Geosciences, 2012, 105 (1), pp.39-48. 10.1007/s00015-012-0090-8 . hal-02178343

HAL Id: hal-02178343

<https://hal.science/hal-02178343>

Submitted on 30 Jun 2021

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

Running title: Radiolarite pebbles from Alpine Oligocene molasses

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Keywords: Western Alps, radiolarite, Jurassic, molasse, Oligocene, subduction wedge.

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 forty 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 Piemonte 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 Piemonte “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 forty 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 *Archeospongoprimum* 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),

149 *Cinguloturris carpatica* Dumitrica, *Zhamoidellum* cf. *argandi* O'Dogherty, Gorican &
 150 Dumitrica (Fig. 4, n° 16) and *Zhamoidellum* cf. *calamin* O'Dogherty, Gorican & Dumitrica
 151 (Fig. 4, n° 22). This assemblage is tentatively assigned to UAZ 6-7 (O'Dogherty et al. 2006).
 152 - 7057-20 contains *Archeodictyomitra apiarum* (Rüst), *Bernoullius* cf. *dicera* Baumgartner
 153 (Fig. 4, n° 29), *Praeconocaryomma* sp. and *Stichocapsa* sp.. It provides a Middle Callovian-
 154 Early Kimmeridgian age (UAZ 8-10). As the occurrence of species *B. dicera* Baumgartner is
 155 uncertain, the upper age limit of this association is tentative.
 156 - 7057-22: correlation to biozone UAZ 7 of Late Bathonian-Early Callovian age is provided
 157 by co-occurrence of *Cinguloturris carpatica* Dumitrica (Fig. 4, n° 4) and *Pseudoristola*
 158 *tsunoensis* (Aita) (Fig. 4, n° 22). Other radiolarians compatible with this age determination are
 159 *Williriedellum* sp. 1 (Fig. 4, n° 23) only documented in Les Gets nappe along with
 160 morphotypes from UAZ 6 and 7 (O'Dogherty et al. 2006) and *Archeospongoprunum elegans*
 161 Wu (Fig. 4, n° 2) also known in this time interval. Other morphotypes present in 7057-14 are
 162 *Arcanica* cf. *leiostraca* (Foreman) (Fig. 4, n° 21), *Archeodictyomitra* sp. (Fig. 4, n° 8),
 163 *Cinguloturris* sp. (Fig. 4, n° 5), *Emiluvia* cf. *chica* Foreman (Fig. 4, n° 27), ?*Fultocapsa* sp.
 164 (Fig. 4, n° 25), *Homoeoparonaella argolidensis* Baumgartner (Fig. 4, n° 28), *Mirifusus* sp.,
 165 *Pseudodictyomitrella* cf. *tuscanica* Chiari, Cortese & Marcucci (Fig. 4, n° 15), and *Tritrabs*
 166 *rhododactylus* Baumgartner (Fig. 4, n° 30).
 167 - 7064-E1 contains *Archeodictyomitra apiarum* (Aita) (Fig. 4, n° 4), *Archeospongoprunum* cf.
 168 *imlayi* Pessagno (Fig. 4, n° 3) and *Cinguloturris carpatica* Dumitrica (Fig. 4, n° 4). This
 169 assemblage is assigned to UAZ 8-11 of Middle Callovian to Early Tithonian age.
 170
 171 In summary:
 172 1. Our chert pebbles range in age from Late Bajocian-Early Callovian (UAZ 5-7) to Middle
 173 Oxfordian-Early Tithonian (UAZ 8-11).

174 2. The oldest pebble could be as old as Late Bajocian (base of UAZ 5) but also as young as
 175 Early Callovian (top of UAZ 7).
 176 3. The youngest pebble could be as old as Middle Oxfordian (7057-14) and as young as Early
 177 Tithonian (7057-14 or 7064-E1).
 178 4. Three pebbles are Middle Jurassic in age. Among them, 7057-22 is restricted to UAZ 7 of
 179 Late Bathonian-Early Callovian age. The two others 7057-3 and -15 are possibly of the same
 180 age but could also be younger (UAZ 5-7 and UAZ 6-7 respectively).
 181 5. Only one pebble (7057-14) is with certainty Late Jurassic in age. The three remaining
 182 pebbles are either Middle or Late Jurassic (7057-8, 7057-20, and 7064-E1).

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184

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

186

187 **4.1. Biochronology**

188

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

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

195 2. the Traversiera massif locality was originally found by R. Polino (Torino), with
 196 radiolarians occurring in phosphate nodules at the base of the sedimentary cover of the
 197 ophiolite (Y. Lagabriele, 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 Piemonte 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* Piemonte 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 Piemonte 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 rule 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 (Lagabriele and Cannat 1990, Lagabriele and Lemoine 1997, Lagabriele 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 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 serpentized 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 been 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.

Acknowledgements

We thank Pierre-Charles de Graciansky (Paris) and Peter O. Baumgartner (Lausanne) for their thorough and insightful reviews. This work was supported by the CNRS-UMR 5276 and the ANR program “ERD-Alps” (Erosion and Relief Development in the western Alps). Chert pebbles were processed in the radiolarian extraction laboratory of Université Lyon 1 (CNRS-UMR 5276). We also thank Arlette Armand (Lyon) for SEM assistance.

References

- Artoni, A., and Meckel, L., D., III (1998). History and deformation rates of a thrust sheet top basin: the Barrême basin, western Alps, SE France. *Geological Society Special Publication*, 134, p. 213-237.
- Barféty, J. C., Lemoine, M., Graciansky, P. C. de, Tricart, P., and Mercier, D. (1995). Notice explicative, Carte géol. France (1/50 000), feuille Briançon (823), Orléans. *Bureau de Recherches Géologiques et Minières*, 180 p.. Geological map by J.C. Barféty, M. Lemoine, D. Mercier, R. Polino, P. Nievergelt, J. Bertrand, T. Dumont, S. Amaudric du Chaffaut, A. Pêcher, G. Montjuvent.
- Baumgartner, P.O., Bartolini, A., Carter, E.S., Conti, M., Cortese, G., Danelian, T., De Wever, P., Dumitrica, P., Dumitrica-Jud, R., Gorican, S., Guex, J., Hull, D.M., Kito, N., Marcucci, M., Matsuoka, A., Murchey, B., O’Dogherty, L., Savary, J., Vishnevskaya, V., Widz, D., Yao, A. (1995). Middle Jurassic to Early Cretaceous radiolarian biochronology of Tethys based on unitary associations, in: Baumgartner, P.O., *et al.* (Eds.), Middle Jurassic to

345 Lower Cretaceous Radiolaria of Tethys: Occurrences, systematics, biochronology. *Mémoires*
 346 *de Géologie*, 23, Lausanne, 1013-1043.
 347
 348 Bernet, M., and Tricart, P. (2011). The Oligocene orogenic pulse in the Southern Penninic
 349 Arc (Western Alps): structural, sedimentary and thermochronological constraints. *Bulletin de*
 350 *la Société Géologique de France*, 182, 25-36. doi: 10.2113/gssgfbull.182.1.25.
 351
 352 Bernoulli, D., and Jenkyns, H. (2009). Ancient oceans and continental margins of the Alpine -
 353 Mediterranean Tethys: deciphering clues from Mesozoic pelagic sediments and ophiolites.
 354 *Sedimentology*, 56, 149-190.
 355
 356 Bill, M., O'Dogherty, L., Guex, J., Baumgartner, P.O., and Masson, H. (2001). Radiolarite
 357 ages in Alpine-Mediterranean ophiolites. Constraints on the oceanic spreading and the
 358 Tethys–Atlantic connection. *Geological Society of America Bulletin*, 113, 129–43.
 359
 360 Bousquet, R., Oberhänsli, R., Goffé, B., Wiederkehr, M., Koller, F., Schmid, S. M., Schuster,
 361 R., Engi, M., Berger, A., and Martinotti, G. (2008). Metamorphism of metasediments at the
 362 scale of an orogen: a key to the Tertiary geodynamic evolution of the Alps. In Siegesmund,
 363 S., Fügenschuh, B., and Froitzheim, N. (Eds.), *Tectonic Aspects of the Alpine-Dinaride-*
 364 *Carpathian System* (pp. 393-411). The Geological Society of London.
 365
 366 Boussac, J. (1912). *Etudes stratigraphiques sur le Nummulitique alpin*. Mémoire explicatif de
 367 la carte géologique détaillée de la France, 662 pp.
 368

369 Caby, R., Michard, A., and Tricart, P. (1971). Découverte d'une brèche polygénique à
 370 éléments granitoïdes dans les ophiolites métamorphiques piémontaises (Schistes lustrés du
 371 Queyras, Alpes françaises). *Comptes Rendus de l'Académie des Sciences Paris*, 273, sér. D,
 372 999-1002.
 373
 374 Chauveau, J. C., and Lemoine, M. (1961). Contribution à l'étude géologique du synclinal
 375 tertiaire de Barrême (moitié nord). *Bulletin de la Carte géologique de France*, 264, 147-178.
 376
 377 Cordey, F. (1992a). Radiolarians and Terrane Analysis in the Canadian Cordillera: the "clastic
 378 approach". In Aitchison, J., and Murchey, B. (Eds.), The significance and application of
 379 Radiolaria to Terrane Analysis. *Palaeogeography Palaeoclimatology Palaeoecology*, 96, 155-
 380 159.
 381
 382 Cordey, F. (1992b). Radiolarian ages from chert pebbles of the Tantalus Formation, Carmacks
 383 area, Yukon Territory. *Geological Survey of Canada Paper* 92-1E, 53-59.
 384
 385 Cordey, F. (1998). *Radiolaires des complexes d'accrétion cordillérains* (210 pp.). Geological
 386 Survey of Canada Bulletin 509.
 387
 388 Cordey, F., and Bailly, A. (2007). Alpine ocean seafloor spreading and onset of pelagic
 389 sedimentation: new radiolarian data from the Chenaillet-Montgenèvre ophiolite (French-
 390 Italian Alps). *Geodinamica Acta*, 20, 131-138.
 391

392 De Wever, P., and Caby, R. (1981). Datation de la base des Schistes lustrés postophiolitiques
 393 par des radiolaires (Oxfordien supérieur-Kimméridgien moyen) dans les Alpes Cottiennes
 394 (Saint-Véran, France). *Comptes Rendus de l'Académie des Sciences Paris*, 292, 467-472.
 395
 396 De Wever, P., and Baumgartner, P.O. (1995). Radiolarians from the base of the supra-
 397 ophiolitic Schistes Lustrés Formation in the Alps (Saint-Véran, France and Traversiera
 398 Massif, Italy). In Baumgartner, P.O., *et al.* (Eds.), Middle Jurassic to Lower Cretaceous
 399 Radiolaria of Tethys: occurrences, systematics, biochronology. *Mémoires de Géologie*, 23,
 400 Lausanne, 725-730.
 401
 402 De Wever, P., Danelian, T., Durand-Delga, M., Cordey, F., and Kito, N. (1987). Datations des
 403 radiolarites post-ophiolitiques de Corse alpine à l'aide des Radiolaires. *Comptes Rendus de*
 404 *l'Académie des Sciences Paris*, 305, 893-900.
 405
 406 Evans, M. J., and Elliott, T. (1999). Evolution of a thrust-sheet-top basin: the Tertiary
 407 Barrême basin, Alpes de Haute Provence, France. *Geological Society of America Bulletin*,
 408 111, 1617-1643.
 409
 410 Ferry, S., Tremblay, S., Guiraud, M. and Cordey, F. (2005). Les molasses rouges paléogènes
 411 du bassin subalpin français. Corrélation avec le bassin helvétique. ASF Association
 412 Sédimentologie France, Octobre 2005 (abstract).
 413
 414 Ford, M., and Lickorish, W. H. (2004). Foreland basin evolution around the western Alpine
 415 arc. In Joseph, P., and Lomas, S. (Eds.). *Geological Society Special Publication*, 39-63.
 416

417 Ford, M., Lickorish, W. H., and Kusznir, N. J. (1999). Tertiary foreland sedimentation in the
 418 Southern Subalpine Chains, SE France: A geodynamic appraisal. *Basin Research*, 11, 315-
 419 336.

420

421 Ford, M., Duchene, S., Gasquet, D., and Vanderhaeghe, O. (2006). Two-phase orogenic
 422 convergence in the external and internal SW Alps. *Journal of the Geological Society*, 163, p.
 423 815-826.

424

425 Gidon, M. (1971). Gap, Geological Map of France 1:50 000. *Bureau de Recherches*
 426 *Géologiques et Minières*.

427

428 Gidon, M., Kerckhove, C., Michard, A., Tricart, P., Gotteland, P., Gout, C., Leblanc, D.,
 429 Lefevre, R., Le Guernic, J., Mégard-Galli, J., and Michel-Noël, G. (1994). Aiguille de
 430 Chambeyron, Geological Map of France 1:50 000. *Bureau de Recherches Géologiques et*
 431 *Minières*.

432

433 Graciansky, P. C. de (1972). Le bassin tertiaire de Barrême (Alpes de Haute-Provence):
 434 relations entre déformation et sédimentation; chronologie des plissements. *Comptes Rendus*
 435 *de l'Académie des Sciences*, Paris, 275, 2825-2828.

436

437 Graciansky, P. C. de, Lemoine, M., and Saliot, P. (1971). Remarques sur la présence de
 438 minéraux et de paragénèses du métamorphisme alpin dans les galets des conglomérats
 439 oligocènes du synclinal de Barrême (Alpes de Haute-Provence). *Comptes Rendus de*
 440 *l'Académie des Sciences*, Paris, 272, 3243-3245.

441

442 Graciansky, P. C. de, Roberts, D. and Tricart, P. (2010). *The Western Alps from rift to passive*
 443 *margin to orogenic belt : an integrated geosciences overview* (432 pp.). Elsevier.
 444

445 Gubler, Y. (1958). Etude critique des sources du matériel constituant certaines séries dans le
 446 Tertiaire des Alpes françaises du Sud: formations détritiques de Barrême, Flysch "Grés
 447 d'Annot". *Eclogae Geologicae Helvetiae*, 51, 942-977.
 448

449 Lagabriele, Y. (2009). Mantle exhumation and lithospheric spreading: an historical
 450 perspective from investigations in the oceans and in the Alps-Appennines ophiolites. *Italian*
 451 *Journal of Geosciences*, 128, 279-293.
 452

453 Lagabriele, Y. and Cannat, M. (1990). Alpine Jurassic ophiolites resemble the modern central
 454 Atlantic basement. *Geology*, 18, 319-22.
 455

456 Lagabriele, Y. and Lemoine, M. (1997). Alpine, Corsican and Apennine ophiolites: the slow-
 457 spreading ridge model. *Comptes Rendus de l'Académie des Sciences*, Paris, 325, sér. II, 909-
 458 20.
 459

460 Lemoine, M. (1983). Rifting and early drifting: Mesozoic Central Atlantic and Ligurian
 461 Tethys. *Initial reports Deep Sea Drilling Project*, US Government Printing Office,
 462 Washington DC, 76, 885-895.
 463

464 Lemoine, M., and Tricart, P. (1986). Les Schistes lustrés piémontais des Alpes occidentales:
 465 approche stratigraphique, structurale et sédimentologique. *Eclogae Geologicae Helvetiae*, 79,
 466 271-94.

467

468 Lemoine, M., Steen, D., and Vuagnat, M. (1970). Sur le problème stratigraphique des
 469 ophiolites piémontaises et des roches sédimentaires associées: observations dans le massif de
 470 Chabrière en Haute-Ubaye (Basses-Alpes, France). *Archives des Sciences*, Genève, 5, 44-59.

471

472 Lemoine, M., Bas, T., Arnaud-Vanneau, A., Arnaud, A., Dumont, T., Gidon, M., Bourbon,
 473 M., Graciansky, P.-C. d., Rudkiewicz, J.-L., Mégard-Galli, J., and Tricart, P. (1986). The
 474 continental margin of the Mesozoic Tethys in the Western Alps. *Marine and Petroleum*
 475 *Geology*, 3, 179-199.

476

477 Lemoine, M., Graciansky, P.-C. de, and Tricart, P. (2000). *De l'océan à la chaîne de*
 478 *montagnes: tectonique des plaques dans les Alpes* (207 p.). Paris : Gordon and Breach
 479 Science.

480

481 Liati, A., and Froitzheim, N. (2006). Assessing the Valais ocean, Western Alps: U-Pb
 482 SHRIMP zircon geochronology of eclogite in the Balma unit, on top of the Monte Rosa
 483 nappe. *European Journal of Mineralogy*, 18, 299-308.

484

485 Manatschal, G., and Müntener, O., (2009). A type sequence across an ancient magma-poor
 486 ocean-continent transition: the example of the western Alpine Tethys ophiolites.
 487 *Tectonophysics*, 437, 4-19.

488

489 Meckel, L., D., III, Ford, M., and Bernoulli, D. (1996). Tectonic and sedimentary evolution of
 490 the Dévoluy Basin, a remnant of the Tertiary western Alpine foreland basin, SE France.
 491 *Géologie de la France*, 2, 3-26.

492

493 Mevel, C., Caby, R., Kienast, J.-R. (1978). Lower amphibolite facies conditions in the oceanic
 494 cruts: example of amphibolitized false-gabbro and amphibolites from an alpine ophiolitic
 495 massif (Chenaillet massif, Hautes Alpes, France). *Earth and Planetary Science Letters*, 39,
 496 98-108.

497

498 Morag, N., Avigad, D., Harlavan, Y., McWilliams, O., and Michard, A. (2008). Rapid
 499 exhumation and mountain building in the Western Alps: Petrology and $^{40}\text{Ar}/^{39}\text{Ar}$
 500 geochronology of detritus from Tertiary basins of southeastern France. *Tectonics*, 27,
 501 doi:10.1029/2007TC002142.

502

503 O'Dogherty, L., Bill, M., Gorican, S., Dumitrica, P., and Masson, H. (2006). Bathonian
 504 radiolarians from an ophiolitic mélange of the Alpine Tethys (Géts Nappe, Swiss-French
 505 Alps). *Micropaleontology*, 51, n° 6, 425-485.

506

507 Rüst, D. (1885). Beiträge zur Kenntniss der fossilen Radiolarien aus Gesteinen des Jura und
 508 der Kreide. *Palaeontographica*, 31, 269-321.

509

510 Schaaf, A., Polino, R. and Lagabriele, Y. (1985). Nouvelle découverte de radiolaires d'âge
 511 Oxfordien supérieur-Kimméridgien inférieur à la base d'une série supra-ophiolitique des
 512 schistes lustrés piémontais (Massif de Traversiera, Haut Val Maïra, Italie). *Comptes Rendus*
 513 *de l'Académie des Sciences*, Paris, sér. II, 14, 1079-1084.

514

515 Schmid, S. M., Fügenschuh, B., Kissling, E., and Schuster, R. (2004). Tectonic map and
 516 overall architecture of the Alpine orogen. *Eclogae Geologicae Helvetiae*, 97, 93-117.

517

518 Schwartz, S., Tricart, P., Guillot, S., Bernet, M., Chamorro-Perrez, E. M., Montagnac, G., and
519 Jourdan, S., *in press*. Source tracing of detrital serpentinite in the Oligocene molasse deposits
520 from the western Alps (Barrême basin): implications for relief formation in the internal zone.
521 *Geological Magazine*.

522

523 Seiders, V.M., and Blome, C.D. (1984). Clast compositions of Upper Mesozoic
524 conglomerates of the California Coast Ranges and their tectonic significance. In M.C. Blake
525 Jr. (ed.), *Franciscan Geology of Northern California* (pp. 135-148). Pacific Section of
526 Economic Paleontologists and Mineralogists 43.

527

528 Sissingh, W. (2001). Tectonostratigraphy of the West Alpine Foreland: correlation of Tertiary
529 sedimentary sequences, changes in eustatic sea-level and stress regimes. *Tectonophysics*, 333,
530 361-400.

531

532 Tricart, P. (1984). From passive margin to continental collision: a tectonic scenario for the
533 Western Alps. *American Journal of Science*, 284, 97-120.

534

535 Tricart, P., Amaudric du Chaffaut, S., Ayoub, C., Ballèvre, M., Caby, R., Gout, C.,
536 Lagabrielle, Y., Leblanc, D., Le Mer, O., Philippot, P., and Saby, P. (2003). Aiguilles-Col
537 Saint Martin Geological Map of France 1:50 000. *Bureau de Recherches Géologiques et*
538 *Minières*.

539

540 Tricart, P., Lardeaux, J.-M., Schwartz, S., and Sue, C. (2006). The late extension in the inner
541 western Alps: a synthesis along the south-Pelvoux transect. *Bulletin de la Société Géologique*
542 *de France*, 177, 299-310.

543

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.

- 569 5- *Cinguloturris* sp., 7057-22, n° 6, 130 µm.
- 570 6- *Archeodictyomitra apiarum* (Rüst), 7057-14, n° 26, 200 µm.
- 571 7- *Archeodictyomitra* sp., 7057-14, n° 28, 150 µm.
- 572 8- *Archeodictyomitra* sp., 7057-22, n° 20, 125 µm.
- 573 9- *Archeodictyomitra* sp., 7057-14, n° 14, 150 µm.
- 574 10- ?*Parvicingula mashitaensis* Mizutani, 7057-14, n° 4, 230 µm.
- 575 11- *Parahsuum carpathicum* Widz and De Wever, 7057-14, n° 15, 150 µm.
- 576 12- *Yaocapsa* sp., 7057-15, n° 4, 160 µm.
- 577 13- *Protunuma* sp., 7057-14, n° 22, 140 µm.
- 578 14- ?*Stichomitra* sp., 7057-08, n° 14, 150 µm.
- 579 15- *Pseudodictyomitrella* cf. *tuscanica* Chiari, Cortese and Marcucci, 7057-22, n° 12, 100
580 µm.
- 581 16- *Zhamoidellum* cf. *argandi* O'Dogherty, Gorican and Dumitrica, 7057-15, n° 16, 130 µm.
- 582 17- *Zhamoidellum ovum* Dumitrica, 7057-14, n° 19, 160 µm.
- 583 18- *Stichocapsa* aff. *robusta*, 7057-08, n° 6, 150 µm.
- 584 19- *Zhamoidellum* sp., 7057-14, n° 27, 185 µm.
- 585 20- *Pseudoristola tsunoensis* (Aita), 7057-22, n° 22, 110 µm.
- 586 21- *Arcanicapsa* cf. *leiostraca* (Foreman), 7057-22, n° 3, 140 µm.
- 587 22- *Zhamoidellum* cf. *calamin* O'Dogherty, Gorican and Dumitrica, 7057-15, n° 7, 120 µm.
- 588 23- *Williriedellum* sp. 1 (O'Dogherty et al. 2006), 7057-22, n° 9, 150 µm.
- 589 24- *Podobursa* cf. *spinoso* Ozvoldova, 7057-14, n° 5, 200 µm.
- 590 25- ?*Fultocapsa* sp., 7057-22, n° 23, 130 µm.
- 591 26- *Acaeniotyle diaphorogona* Foreman, 7057-14, n° 1, 200 µm.
- 592 27- *Emiluvia* cf. *chica* Foreman, 7057-22, n° 15, 200 µm.

593 28- *Homoeoparonaella argolidensis* Baumgartner, 7057-22, n° 1, 200 µm.

594 29- *Bernoullius* cf. *dicera* (Baumgartner), 7057-20, n° 6, 150 µm.

595 30- *Tritrabs rhododactylus* Baumgartner, 7057-22, n° 18, 200 µm.

596 31- *Mirifusus* sp., 7057-14, n° 3, 250 µm.

597

598 **Fig. 5.** Crustal cross-section model proposing an evolution for the southern Western Alps

599 during the Early Oligocene. At that time, the Piedmont thrust sheets already stacked in the

600 upper Cretaceous-Paleocene subduction accretionary wedge underwent severe syncollision

601 shortening. It resulted in a major orogenesis so that erosion fed abruptly the peripheral

602 molasses in margin-derived and ocean-derived clasts whose metamorphic signatures range

603 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
<i>Acaeniotyle diaphorogona</i> Foreman 4-22							X
<i>Arcanica</i> cf. <i>leiostraca</i> (Foreman)			X				
<i>Archeodictyomitra apiarum</i> (Rüst) 8-22					X	X	X
<i>Archeodictyomitra</i> sp.			X				X
<i>Archeospongoprimum elegans</i> Wu 6-?			X				
<i>Archeospongoprimum</i> cf. <i>imlayi</i> Pessagno	X					X	
<i>Bernoullius</i> cf. <i>dicera</i> (Baumgartner) 3-10					X		
<i>Cinguloturris carpatica</i> Dumitrica 7-11		X	X	X		X	X
<i>Cinguloturris</i> sp.			X				
<i>Emiluvia ordinaria</i> Ozvoldova 9-11							X
<i>Emiluvia</i> cf. <i>chica</i> Foreman 3-18			X				
? <i>Fultocapsa</i> sp.			X				
<i>Homoeoparonaella argolidensis</i> Baumgartner 4-11			X				
<i>Mirifusus</i> sp.			X				X
<i>Orbiculiformella</i> sp.	X						
<i>Parahsuum carpathicum</i> Widz & De Wever 7-11							X
? <i>Parvicingula mashitaensis</i> Mizutani 8-15							X
<i>Podobursa</i> cf. <i>spinosa</i> Ozvoldova 8-13							X
<i>Praeconocaryomma</i> sp.				X	X		
<i>Protunuma</i> sp.							X
<i>Pseudodictyomitrella</i> cf. <i>tuscanica</i> Chiari, Cortese & Marcucci			X				
<i>Pseudoristola tsunoensis</i> (Aita) 6-7			X				
<i>Pseudoeucyrtis</i> sp.							X
<i>Stichocapsa robusta</i> Matsuoka 5-7	X						
<i>Stichocapsa</i> aff. <i>robusta</i> Matsuoka				X			
<i>Stichocapsa</i> sp.	X				X		
? <i>Stichomitra</i> sp.				X			
<i>Tritrabs rhododactylus</i> Baumgartner 3-13			X				
<i>Williriedellum</i> sp. 1 (O'Dogherty et al. 2006)			X				
<i>Yaocapsa</i> sp. 5-6		X					
<i>Zhamoidellum ovum</i> Dumitrica 9-11							X
<i>Zham.</i> cf. <i>argandi</i> O'Dogherty, Gorican & Dumitrica 6-7		X					
<i>Zham.</i> cf. <i>calamin</i> O'Dogherty, Gorican & Dumitrica		X					
<i>Zhamoidellum</i> 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

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5