Mantle exhumation at magma-poor passive continental margins. Part I. 3D architecture and metasomatic evolution of a fossil exhumed mantle domain (Urdach lherzolite, north-western Pyrenees, France)

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SUPPLEMENTARY MATERIAL : TEXT FILE

Content : 1. text of sections 3.2.4, 3.3.3 and 5

2. Detailed captions of figures S1 to S11 and tables S12 to S20

3.2.4 the Urdach crust-mantle detachment : microscopic study and mineralogy

Microscopic observation of samples URD1, URD4, URD5 and URD12 confirm that the Urdach lherzolites are locally intensively serpentinized with typical mesh texture and veining development, but that most of the samples preserve relicts of primary minerals (fig. S3). However, large volumes of the serpentinized mantle underwent by place substantial carbonate veining as well as the complete dissolution of the primary silicates and their replacement by calcite (carbonation). This is well observed in the Bilatre quarry ophicalcite (sample URD1) where the serpentinites along the edges of the calcite veins are fully carbonated (fig. S4). Some relicts of serpentine mesh are observed a few millimeters away from the veins, as dark, dusty inclusions in calcite. In both URD1 and URD12 samples, the variously carbonated mantle is dissected by a network of orthogonal sparitic calcite veins with complex crosscutting relationships (fig. S5).

In hand specimen, sample URD1 exhibits a 3 cm-thick composite vein composed of a core of sheared elongated serpentine leaves separated locally by cataclastic calcite veins (fig. S4). Thin section observation shows that pervasive carbonation occurred synchronously with calcite veining, in successive stages. Undeformed millimeter wide veins filled with sparitic calcite (veins 1) are crosscut by shear zones centimeter in size paralleling deformed veins (veins 2). Veins 2 are in turn crosscut by undeformed or poorly sheared calcite veins (veins 3). Some calcites display a botryoidal habit in veins showing multi-phased growth. In URD1 sample, co-crystallization of carbonate and serpentine is testified by the occurrence of lenticular flakes of light green serpentine between sparite calcite precipitates. Aggregates of inframillimetric rhomboidal carbonates are included into the serpentine flakes (fig. S4D1 and D2).

Microscopic study of sample URD12 (fig. S5) confirms that the serpentinized mantle was affected by pervasive shearing during or after the carbonation. This sample is composed of a part of serpentinized mantle and a part of carbonated mantle. Both parts are cross-cut by numerous shear zones and calcite veins. At the microscopic scale, the carbonated mantle exhibits a foliation defined by parallel shear zones with calcite grain reduction. This foliation parallels the limit between the carbonated and the non-carbonated mantle, which also appears as a main shear zone (fig. S5A and B).

Finally, the mesoscopic and microscopic observations of ultramafic samples from the Bilatre quarry collectively reveal that the Urdach ophicalcites have recorded a complex history of syn-tectonic mantle carbonation.

Based on thin section observation, the albitite-like sample URD9-1 is quartz-free and composed of large and fully sericitized inframillimetric feldspars surrounded by dominant, equigranular millimetric albite crystals. It exhibits numerous well-crystallized zircons (hundreds of microns in size), like the albitite dikes described by Pin et al. (2001, 2006). Millimeter-wide shear zones exhibiting cataclastic albites in a groundmass of very small muscovites (sericite) cross-cut the sample (fig. S6A1 and S7). Electron-probe microanalyses were performed on various muscovite, albite and 30 zircons from this sample (table S4). Meter-wide veins sampled close to the albitite-like URD9-1 are made of green chlorite flakes forming large rosettes associated with large hydrothermal quartz crystals hosting numerous fluid inclusions (samples URD9-2: fig. S7C; and samples URD9-b and URD9-f, microscopic view not shown). These chlorite-rich veins display quartzose borders showing two generations of quartz: the first one consists of large crystals, the second one is composed of small crystals in geodic cavities (sample URD9-c, microscopic view not shown). Shear zones in which the chlorites are fragmented and recrystallized in small crystals cross-cut the entire samples. Microprobe analyses indicate that samples URD9-b, URD9-c and URD9-f are Cr-muscovite-rich (fuchsite) together with various amount of quartz, clinochlore and rutile (table S5, S6, S7). This Cr-rich mineralogical association has affinity with listvenite assemblages (see more details in subsection 3.3.3 below).

Large millimetric flakes of dark green static chlorite, often arranged in rosettes, are the dominant component of the chloritite from the Urdach breccia (sample BCOR115), together with numerous zircons of hundreds of microns across (fig. S7D). This rock is devoid of any deformation. It may derive from the disaggregation of either a metasomatic chlorite vein from the crust-mantle detachment similar to veins in samples URD9-2 or of the border of an albitite dike intrusive in the mantle rocks. Electron-probe microanalyses were performed on on 12 chlorites and 7 zircons from this sample (table S8). By contrast with the chlorites from the Saraillé crust-mantle detachment and cover décollement, these Mg-chlorites (clinochlore) are Cr-free. The BCOR115 zircons were dated by in situ U/Pb LA-ICP-MS (see section 5 and fig. S6).

3.3.3 the Urdach cover *décollement* : microscopic study and mineralogy: evidence for metasomatic transformations

As shown by the observation of sample URD17b (sub-unit a) thin section, the lherzolites lying against the Urdach cover décollement, north-east of Col d'Urdach, are deeply serpentinized with well-developed mesh textures and limited marks of pervasive carbonation (fig. 8B). Most pyroxenes are changed to bastite with rare cores containing relics of fresh minerals. Small spinels are widespread in the groundmass. A rough tectonic fabric is marked by the flattening of the serpentinized olivine that parallel the dark septae of the mesh texture. Some calcite-rich fractures cross-cut the lherzolites. Mineral microprobe analyses of sample URD17b reveal the presence of relict cpx and metamorphic phases such as Cr-rich clinochlore and magnesian amphiboles replacing pyroxenes (table S9). The mesh texture groundmass is composed of pseudomorphic serpentines whose SiO_2 and MgO contents vary between 39 and 45 wt%, and 27 and 31 wt % respectively. Their FeO tot content ranges from 5 to 8% and they contain a rather high amount of Al (Al_2O_3 = 6 to 8 %). Apart from the Al content, these compositions fall in the range of compositions of serpentines from oceanic or ophiolitic environments. We provide hereafter some compositions for reference. In the serpentine from the Iberia margin, SiO_2 content varies between 38 and 42 wt% and MgO content varies between 28 and 38 wt%; FeO content ranges from 4 to 7 wt% (Agrinier et al., 1988). In the ophiolitic Chenaillet serpentinites (French western Alps), SiO_2 and MgO contents vary between 44 and 38 wt %, and 43 and 34 wt % respectively and FeO content ranges from 2 to 9 wt % (Lafay et al., 2017). The FeO content ranges from 2 to 8 wt% and may reach 12 wt % in serpentine from mesh textures of the South West Indian Ridge (Rouméjon et al., 2015). It ranges from 1.3 to 6.9 wt % in serpentine from ophiolites in Mexico (Gonzalez-Mancera et al., 2009), and may reach up to 19% wt % in chrysotile from Quebec (Faust and Fahey, 1962). This comparison points to a rather high Al_2O_3 content of the Col d'Urdach serpentine compared to the composition of serpentines from the Indian Ridge and from the Chenaillet (Al_2O_3 content between 0.9 and 4 wt % and 0.2 to 3.4 wt % respectively). This high content most likely records the presence of bastitized cpx as already reported by Agrinier et al., (1988) who studied composition variations of hydrated minerals in the Iberia margin mantle. Here, high Al_2O_3 content (up to 5.38 wt %) are found in serpentine after orthopyroxene whereas serpentine from olivine are almost Al-free. Alternatively Padrón-Navarta et al., (2013) have shown that Al-content in natural antigorite changes substantially as a function of pressure and temperature in response to Tschermak's exchange in antigorite solid solution. A higher Al-content being favored at lower pressure and higher temperature. Note that serpentine may incorporate high contents of Al as shown by analyses of metasomatic komatiite (Al_2O_3 content max 15.8 %, Albino, 1995) indicating that the Urdach compositions are not uncommon.

Thin section observation of the vein-textured metasomatic assemblages from the Urdach cover décollement (sample URD17a, sub-unit b) reveals an intimate intergrowth of fibrous calcite and serpentine (fig. S8F). Two different generations of serpentine can be distinguished owing to the habitus of the fiber intergrowths. Ante- to syn-deformation serpentine are sheared and tightly folded in the intercept of conjugate shear zones whereas another serpentine generation corresponds to acicular post-kinematic crystals. These microtextural relationships indicate that serpentine growth occurred synchronously with the calcite crystallization (with minor edenite), during and after faulting activity along the Urdach cover décollement. Sample URD17a serpentines have SiO_2 content between 42 and 45% and MgO content between 32 and 35%. They have low relatively Al and Fe content (FeO and Al_2O_3 contents between 5 and 8% and between 2 and 3%, respectively: table S10), compared to the in-situ pseudomorphic serpentines from the massive lherzolite of sub-unit a (sample URD17b). These relatively low Fe and Al contents are consistent with their occurrence in veins as fluid precipitates. Dolomite was not found in this vein system. Indeed, microanalyses of fifteen carbonate crystals from sample URD17a reveal that only calcite crystallized together with serpentine in this deforming zone, close to the mantle body (table S10). Still in sub-unit b, the carbonates forming the large veins situated less than one meter to the north of the cover décollement fault (sample URD16, fig. 10) display both syn- and post-kinematic characters. Under the microscope, static assemblages are composed of aggregates of carbonates isolating millimetric areas filled with small chlorite flakes devoid of preferred orientation, and locally arranged in small, contiguous rosettes (fig. S8 E). Brownish areas rich in truncated clusters of millimeter-sized opaque grains probably correspond to relict of mesh texture. This would imply that totally carbonated lherzolite clasts were incorporated in carbonate veins situated some meters away from the Urdach mantle. Surprisingly, sample URD16 static chlorites are mostly Cr-poor clinochlores (Cr_2O_3 content between 0.02 and 0.79 %; SiO_2 content between 32 and 34%; MgO content between 28 and 30%, table S11) indicating a post-deformational fluid source devoid of ultramafic influence. The sigmoidal lenses alternating with the calcite veins are all cataclastic carbonate breccias with numerous evidence of hydrofracturing brecciation as shown by microscopic study of sample URD13 texture (fig. S8A). These cataclastic carbonates derive from a fully recrystallized sedimentary protolith, a Liassic limestone belonging to the basal layers of the Mail Arrouy pre-rift sequence as indicated by the BRGM geological map (Casteras et al., 1970). These brecciated limestones also contain chlorite aggregates that have crystallized together with calcites, accounting for important fluid circulation in the sigmoidal lenses of metasediments associated with veins. According to microprobe analyses, URD13 chlorites are also clinochlores with variable but relatively low Cr_2O_3 content (0.9 wt % max) (table S12). This confirms some chemical transfers from mantle rocks by means of fluid exchange along the cover décollement.

The cores of the orange-colored dolomitic lenses of sub-unit c (samples URD18 : fig. S8) and URD20 (not shown), consist of a tectonic microbreccia showing angular clasts of recrystallized dolomitic material separated by veins entirely composed of euhedral micro-dolomites. We performed electron probe micro-analyses of eighteen dolomitic crystals from sample URD18 in order to detect heterogeneities between clasts and cement (table S13). A striking feature here is the high level of recrystallization of the entire dolostone as shown by the presence of large euhedral crystals. MgO and CaO concentrations are comprised between 20 - 22% and 31 - 32%, respectively. We found only trace amounts of Cr and Ni and less than 1.38% FeO. The homogeneous composition of both clasts and their host veins argues for a closed fluid system during deformation.

Sample URD14 (sub-unit c) is a black marble crossed-cut by numerous white calcite veins at the hand specimen scale. Thin section observation also reveals a tight micro-veining, orthogonal to a schistosity marked by the flattening of carbonate beds rich in bioclasts and deformed microfossils (fig. 10C). The fossiliferous beds contain abundant foraminiferas, mostly *Miliolidae*, representative of Liassic platform environments (J. Canérot, pers. comm.). Sample URD14 is also marked by the presence of numerous pyrite crystals. Microprobe analyses indicate that the carbonates are mostly calcite and confirm the occurrence of pyrite (table S14). It is worth noting that a RSCM temperature of 300°C was obtained for sample URD14 (Corre et al., in prep.).

Samples URD19 and URD15 located 30 m away from the cover décollement fault in sub-unit d (fig. 10A2 and D), display peculiar aspects and compositions. URD19 is a dolomitic breccia with recrystallized geodic dolomites (fig. S8H, I). Microprobe analyses show that large calcite crystals are associated with dolomite in the veins, with rare white mica (table S15). Dolomite contain small amounts of FeOtot (up to 3.4%). The veins are filled with an assemblage of opaque minerals including sphalerite and pyrite associated with possible pyrrhotite (FeO = 62.18%) (fig. S8 I). Thin section observation of sample URD15 (fig. S8C) reveals the presence of large areas of micro-calcite that contain striated zones of a dusty black material (not shown). These dark areas represent ghosts of fully carbonated pyroxenes and relicts of mesh textures, thus confirming their origin from a deeply transformed mantle protolith. Calcites contain trace amounts of Fe (0.5% FeO). They are associated with rare dolomite containing some amount of Fe (FeO=2.3%) (table

S16). Small aggregates of quartz crystals are associated with the calcites. The rock is cross-cut by shear bands defining a rough foliation. The shear bands contain a carbonated ultramafic material with relicts of pyroxenes, well observed in some large calcite crystals. Flakes of partially sheared green pleochroic mica crystallized in the deformed bands (fig. S8C). They contain 22-26% Al_2O_3, 6-9% K_2O, 3-4% MgO, 0-2% NiO and 2-7% Cr_2O_3 (on the basis of fourteen microprobe analysis: table S16). These Cr-rich white micas are Cr-muscovite (fuchsite), a mineral frequently encountered in ultramafic environments. The association of calcite, quartz, Cr-muscovite and accessory chlorite in metasomatic zones on the site of former ultramafic material defines the rock-type *listvenite* (e.g. Buisson and Leblanc, 1986). Listvenites often contain additional serpentine, talc and chlorites. The formation of listvenites is linked to carbonation and silicification by CO_2-rich fluids that circulate through intensively sheared peridotites (Harlov and Austrheim, 2013, with references therein). In addition, it must be noticed that URD15 is largely invaded by pyrite that crystallized in grains up to some mm wide (fig. 10D). Carbonation and silicification implies the circulation of a great amount of fluids able to dissolve the mantle silicates and to precipitate the carbonates and the quartz. However, while listvenitization exert a fundamental change in rock texture and mineralogy, it has been shown that, with the exception of volatiles, the primary ultramafic rock composition (e.g content in MgO + CaO/SiO_2) can be preserved (Falk and Kelemen, 2015). The occurrence of listvenite implies that a tectonic slice of deeply metasomatized mantle rocks is present here. Due to poor exposure conditions, it is not possible to precise the structural position of this mantle unit. It is probably thrusted over the tectonic lenses of Mesozoic carbonates due to a local reverse fault as represented in figure 10.

Our knowledge of the metasomatic mineralogical assemblages from the Urdach cover décollement is completed by the analysis of the Peillou section rock suite. Sample BCOR300a consists of submillimetric albite crystals with diffuse margins containing patches of thinly crystallized sericite. The largest albite crystals are surrounded by a chlorite-rich groundmass that contains large millimetric euhedral zoned zircons (fig. S8J). Locally, shear bands with small euhedral albites and micas cross-cut the thin section. The chlorites of sample BCOR300a are either Mg- or Fe-rich, Cr-free clinochlores (MgO = 30 to 17 wt% and FeO Tot = 17 to 5 wt%) (table S17) similar to those of sample BCOR115. The analyzed micas are muscovite. This zircon-bearing albitite has an unclear structural position like sample URD9-1 albitite. It probably represents a former dike, intrusive into the Urdach mantle, that was exposed close to the seafloor during mantle exhumation and that was later incorporated into the Peillou complex fault zone as the result of the Pyrenean compressional tectonics.

In thin section, sample BCOR300b is dominated by the intergrowth of large talc and chlorite crystals (fig. S8K). The chlorites are Cr-rich, Mg-clinochlores (Cr_2O_3 content = 0.3 to 1.4 wt% based on six analyses: table S18). Such an association of talc and Cr-rich chlorite is also largely present in the Saraillé massif (see companion paper). This talc-chlorite association thus appears as an important characteristic of the contact zones between mantle rocks and the hanging wall material, whatever the latter could be. As a consequence, rock-type BCOR300b can be regarded as an equivalent of the metasomatic pink talcschists exposed along the cover décollement of the Saraillé massif (e.g. sample BCOR30) (see companion paper).

Sample BCOR300c (fig. S9) comes from a tectonic breccia that incorporates clasts of various origin. Most of them derive from Triassic protoliths, such as brecciated and foliated orange dolostones and minor meta-ophites. Microprobe analyses confirm the presence of largely recrystallized dolomite (some of them are iron-rich) and of albite that replaces the plagioclase microliths in a meta-ophite clast (table S19). The meta-evaporite BCOR300e is mostly composed of small interpenetrated anhydrite crystals (microprobe identification of S) with minor inclusions of euhedral calcites and dolomites and a small amount of newly formed quartz (table S20).

5 LA-ICP-MS U-Pb dating of zircons

U-Pb geochronology of zircon was conducted in-context (i.e. in thin-sections) by in-situ Laser Ablation - Inductively Coupled Plasma - Mass Spectrometry (LA-ICP-MS) at Géosciences Rennes using an ESI NWR193UC Excimer laser coupled to a quadripole Agilent 7700x ICP-MS. During the course of an analysis, the signals of ^{204}(Pb+Hg), ^{206}Pb, ^{207}Pb, ^{208}Pb, ^{232}Th and ^{238}U masses are acquired. No common Pb correction was applied owing to the large isobaric interference with Hg. The ^{235}U signal is calculated from ^{238}U on the basis of the ratio $^{238}U/^{235}U=137.88$. For more information on the analytical protocol and the settings of the instruments, see Ballouard et al. (2015) as well as table S2. Data were corrected for U–Pb and Th–Pb fractionation and for the mass bias by standard bracketing with repeated measurements of the GJ1 zircon standard (Jackson et al., 2004). Repeated analyses of the Plešovice zircon standard (Sláma et al., 2008) treated as unknown were used to control the reproducibility and accuracy of the corrections (see table S2) and yield a concordia age of 337.7 ± 3.6 Ma (MSWD=0.54, N=9). Data reduction was carried out with the GLITTER® software package developed by the Macquarie Research Ltd. (Van Achterbergh et al., 2001). Concordia diagrams were generated using Isoplot/Ex (Ludwig, 2001). All errors given in table S3 are listed at one sigma, but where data are combined to calculate an age, the final results are provided with 95% confidence limits.

5.1. In context zircon U/Pb dating of a sericite-albitite in contact with the Urdach mantle rocks: sample URD9-1

Zircon grains are generally big in size (0.5-1.5 mm) and characterized by a relatively homogeneous center surrounded by lighter concentric zoning (Fig. S6A). Thirty-four analyses out of 7 large zircon grains were performed directly in thin section (table S3). The common Pb contents are usually low (*f*206% between 0 and 4.7%). These zircon grains have very variable Th, U and Pb contents (114-9816 ppm, 46-573 ppm and 1-57 ppm respectively) yielding high and variable Th/U ratios (2 to 33). Unusually high Th/U ratios have already been described in some zircon grains from carbonatite and nepheline syenite pegmatite (up to 1000; Belousova et al., 2002).

In a Tera-Wasserburg diagram (Fig. S6B) the data plot in a discordant to concordant position (depending on their common Pb contents). Seven concordant analyses within error yield a Concordia date of 112.9 ± 1.6 Ma (Fig. S6B inset). The positions of the remaining data are interpreted as the consequence of the presence of common Pb and/or a slight Pb loss. The mean $^{206}Pb/^{238}U$ date for all the data but one is equivalent within error at 111.7 ± 0.8 Ma (MSWD=2.7; Fig. S6C).

5.2. In context zircon U/Pb dating of a clast of static chloritite from the Urdach breccia: sample BCOR115

Zircon grains are generally large (0.5 mm) and characterized, in cathodoluminescence, by some grains with rather homogeneous dark-cores surrounded by concentric lighter zonings (Fig. S6D) while others are homogeneous with a very faint luminescence. Twenty-nine analyses out of 8 zircon grains were performed in thin-section (table S3). In some of the analyzed grains, the common Pb contents can be very high (*f*206% up to 57%). Analyses are variable in terms of Th, U and Pb contents (311-19413 ppm, 14-1104 ppm and 2-122 ppm respectively). These zircon grains also yield highly variable albeit very high Th/U ratios (4-35). Plotted in a Tera-Wasserburg diagram (Fig. S6E), the data are sub-concordant to discordant and yield a lower intercept date of 109.4 ± 1.2 Ma (MSWD = 2.7). If the isochron is forced to the common Pb composition at ca. 110 Ma according to Stacey and Kramers' model (1975), we obtain a similar date of 110 ± 1.2 Ma (MSWD = 3.2, not shown).

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Captions to figures and tables of Supplementary Material

Figure S1. Field aspects of the Urdach breccia and views from the Mer de Her area.

A: a clast of poorly sheared andalusite schist rarely observed in the Urdach breccia (close to Soum d'Ombrets). B: mylonitic gneiss very frequently observed in the Urdach breccia. C: high angle dipping of the foliation in the lens of Paleozoic material (Silurian?) welded on the Urdach mantle at Mer de Her. D, E, F: various aspects of the breccia in the Mer de Her area. Breccia is welded by a quartz-rich cement containing by place abundant concentrates of iron oxides (D and F); it suffered local dissolution (cellular aspect due to vacuolar quartz cement, D). The clasts are mostly mylonitic quartzites. G: tectonic breccia found as a clast in the Urdach breccia close to Soum d'Ombrets. It is composed of clasts from a mylonitic micaschist. Some of the clasts underwent very little relative displacement.

Figure S2. Deformation and fluid-rock interactions in the Mesozoic cover above the Urdach cover décollement.

A: lenticular fabric and conjugate shear zones in the Jurassic marbles exposed along the trail to Soum de Ségu (cover décollement at hill 488). B: calcite veining (Granges Lacues). C: N-S vertical schistosity in the Jurassic marbles exposed some meters beneath the trail to Soum de Ségu (cover décollement at hill 488). D: foliated tectonic breccia (clast boudaries are outlined by conjugate shear planes).

Figure S3. Microscopic view of the serpentinized Urdach mantle (sample URD4).

Serpentinizaton is not complete and relic olivines and pyroxenes are still visible through the pervasive serpentine mesh texture.

Figure S4. The Bilatre quarry ophicalcites: sample URD1, hand specimen and microscopic aspects.

A1: photograph of hand specimen. A2: structural interpretation. The sample shows a 3 centimeters thick shear zone with light serpentine fibers and calcite intergrowths, defining a curved foliation (f). At least 3 generations of calcite veining can be identified. Veins 1 may have developed before the shearing event, veins 2 are emplaced during the shearing event and veins 3 crosscut f. B: microscopic view of vein 2 showing sheared serpentine and calcite. C: microscopic view of veins 1 and 2 relationships. D1 and D2: close up on microscopic evidence for co-genetic relationships between serpentine in veins and carbonates (most probably calcite) (serp. = serpentine).

Figure S5. The Bilatre quarry ophicalcites: sample URD12, hand specimen and microscopic aspects.

A: photograph of hand specimen and its structural interpretation. The sample shows a large portion of carbonated mantle (light blue) crosscut by few calcite veins. B: microscopic view (location in A) showing the transition from the serpentinized mantle (green) to the fully carbonated area. This transition corresponds to numerous shear zones affecting both carbonates and serpentine minerals in the serpentinzed mantle. A shear zone marks the sharp boundary with the fully carbonated mantle. This shear zone might be syn- or post-carbonation. C and D: detailed microscopic views showing evidence for the development of syn-carbonation shear zones (carb. = carbonated, serp. = serpentine, lherz. = lherzolite, amphi = amphibole, cpx = clinopyroxene).

Figure S6. In situ U/Pb zircon dating.

A1: microscopic view of sample URD9-1. A2: cathodoluminescence picture of a typical zircon grain from sample URD9-1. B: Tera-Wasserburg diagram for sample URD9-1 (inset shows the concordia age). C: mean $^{206}Pb/^{238}U$ date obtained from the zircon analyses (sample URD9-1). D1: microscopic view of sample BCOR115. D2: cathodoluminescence picture of a typical zircon grain from sample BCOR115. E: Terra-Wasserburg diagram for sample BCO115.

Figure S7. Metasomatic rocks of the crust-mantle detachment.

A, B and D: microphotographs of the dated samples URD9-1 and BCOR115. C: microphotograph of the chlorite-schist URD9-2 containing Cr-muscovite (alb = albite, zr = zircon, chl = chlorite, Cr-ms = Cr-muscovite : fuchsite).

Figure S8. Microphotograph of the main rock-types composing the cover décollement fault rocks along (i) the “ball trap” (A to I, location of samples in fig. 10) and (ii) the Peillou sections (J, K, L).

A: URD13, hydrofractured dolostone. B: URD14, sheared fossiliferous black limestone. C: URD15, listvenite. D, E and F: calcite veins with static chlorites and possible relict of mesh texture (carbonated mantle rock?) (URD16) or deformed and non deformed serpentine sheets (URD17a). G: URD18: monomictic dolostone tectonic breccia (dol = dolomite). H and I: URD19, dolostone breccia with calcite veining (calc) and sphalerite (sphal.). J, K and L: rocks from the Peillou section. Zircon-bearing albitite (BCOR300a), chlorite-talc-schist (BCOR300b), meta-evaporite (anhydrite, BCOR300e).

Figure S9. Triassic tectonic breccia at Peillou: sample BCOR300c.

A: microscopic view (natural light) showing a millimeter-sized clast of meta-ophite in a groundmass of dolostone micro-breccia. B: BSE image of the meta-ophite clast shown in A with the location of analyzed albites (points 56 to 61). C: additionnal microscopic view showing various clasts in the same groundmass of dolostone micro-breccia (dol. = dolomite).

Figure S10. Lavas in the Late Albian flysch at Bilatre : macroscopic aspects.

A, B, C: illustration of the altered and non altered spherulitic facies. D, E: flysch inclusions in the lavas.

Figure S11. Lavas in the Late Albian flysch at Bilatre : microscopic aspects.

A: sample BCOR394, contact between flysch sediments and fresh lava. B: sample BCOR274. Typical spherulitic texture. Note flattening of spherulites along the doted white line (syn- or post-emplacement). C: close up of hyaloclastite fragment. D: a millimeter-sized clast from a massive lava fragment with radial microlitic texture. E: details of quartz fragments (note the presence of both euhedral crystals and polycrystalline aggregates). F: typical poorly deformed spherulitic texture.

Table S1. Major and trace element analysis of handpicked glassy spherulites from Bilatre (sample BCOR394d). Major elements as oxides wt%, trace elements in ppm. Total iron as Fe_2O_3; LOI: Loss On Ignition at 1050°C. ICP-AES data, Plouzané. Analytical methods described in Cotten et al. (1995).

Table S2. Operating conditions for the LA-ICP-MS equipment.

Table S3. U-Th-Pb data obtained on zircon grains by LA-ICP-MS

All errors are reported at 1 sigma. For sample URD9-1, data in bold were used to calculate the concordia age. Concordance was estimated as Conc% = (Age ($^{206}Pb/^{238}U$) x 100)/(Age($^{207}Pb/^{235}U$)) f206% = ($^{207}Pb/^{206}Pb_m$ - $^{207}Pb/^{206}Pb^*$)/($^{207}Pb/^{206}Pb_c$- $^{207}Pb/^{206}Pb^*$)x100

Tables S4 to S20. Microprobe mineralogical analyses.

Analytical techniques. The chemical compositions of minerals was acquired by microprobe analysis on five samples and are listed in tables 1 to 5. The major-element compositions of the minerals were determined by electron microprobe analysis using a CAMECA SX100 at Service Commun de Microsonde Ouest (SCMO), Plouzané, France. using a CAMECA SX100 microprobe, operated at 15 kV, 20nA, spot size 5 µm and 10 s counting time on peak and 5 s on background. The EPMA instrument was equipped with five WDS detectors with LIF, PET, and TAP crystals, and all elements were assigned to specific detectors to be measured 5 + 5 concurrently per run of ~ 30 s total duration. Standards were natural albite (Na, Si), orthoclase (K), corundum (Al), wollastonite (Ca), forsterite (Mg), $MnTiO_3$ (Mn, Ti), andradite (Fe) and chromite (Cr). Raw spectral data were ZAF-corrected using the phi-rho-Z protocol of Pouchou and Pichoir (1984) known as 'PAP'. Element contents were recalculated to oxides by stoichiometry, total iron content is represented as FeO. Limits of detection are: 0.01 wt% (Mn, Ti, Fe, Cr), 0.05 wt% (Ca, Si, K) and 0.10 wt% (Al, Mg, Na). Main element oxide contents in wt% were recalculated into mineral compositions in atoms per formula unit – apfu using standard routines. Volatiles contents in H_2O and/or CO_2 were calculated by balance of the sum total with 100.00 wt%. Mineral names are abbreviated according to recommendations by Whitney and Evans (2010).