

Spandler et al., 2018, Neodymium isotope disequilibria in subducted sediments, and potential consequences for subduction-zone recycling: *Geology*, <https://doi.org/10.1130/G45147.1>.

Appendix DR1. Geological setting and description of samples

Samples used in this study were sourced from the well-studied high-pressure (HP) to ultrahigh-pressure (UHP) metamorphic belts of New Caledonia, Lago di Cignana (Zermatt Saas Unit; Western Italian Alps) and Dora Maira (Western Italian Alps).

NEW CALEDONIA

New Caledonia is located at the northernmost end of the Norfolk Ridge in the south-west Pacific. The north-eastern portion of the main island of New Caledonia comprises an extensive HP metamorphic belt (Aitchison et al., 1995; Cluzel et al., 2012) that transitions in metamorphic grade from sub-greenschist facies in the west to eclogite facies to the north-east, although much of the metamorphic grade change is due to juxtaposition of rocks of different metamorphic grade by normal faulting (Rawling and Lister, 2002; Both phases belong to the peak metamorphic mineral assemblage.). Most of the belt below eclogite-facies consists of a metasedimentary package (sandstone, shale and marl protoliths), with intercalations of metavolcanic units (rhyolite, basalt), and Cu-Zn-Pb sulfide mineralisation. These rocks are divided in two units; the Koumac Unit to the west and below the lawsonite-in isograd, and the Diahot Blueschists that are above the lawsonite-in isograd (Fig. A1; Pirard and Spandler, 2017). The highest grade eclogite-facies rocks (Pouebo Eclogite Mélange) crop out on the east coast and along the Pam Peninsula as a tectonic melange of mafic eclogites and garnet blueschists, pelitic schists and gneisses, serpentinite, and talc and chlorite schists (Spandler et al., 2008).

The belt is interpreted to represent a package of oceanic crust and sediments derived from continental and proximal volcanic arc sources (Spandler et al., 2004; Pirard and Spandler, 2017) that was subducted and metamorphosed in the time between 44 and 38 Ma (Spandler et al., 2005; Taetz et al., 2016). Exhumation to upper crustal depths was likely completed by 34 Ma (Baldwin et al., 2007).

Two metasedimentary samples used in this study derive from the Diahot Blueschists (Fig. A1). These samples have been demonstrated to contain detrital material of diverse age and Hf isotopic composition (Pirard and Spandler, 2017), and therefore were chosen to test for Nd isotope equilibration during metamorphism to high-grade blueschist-facies conditions.

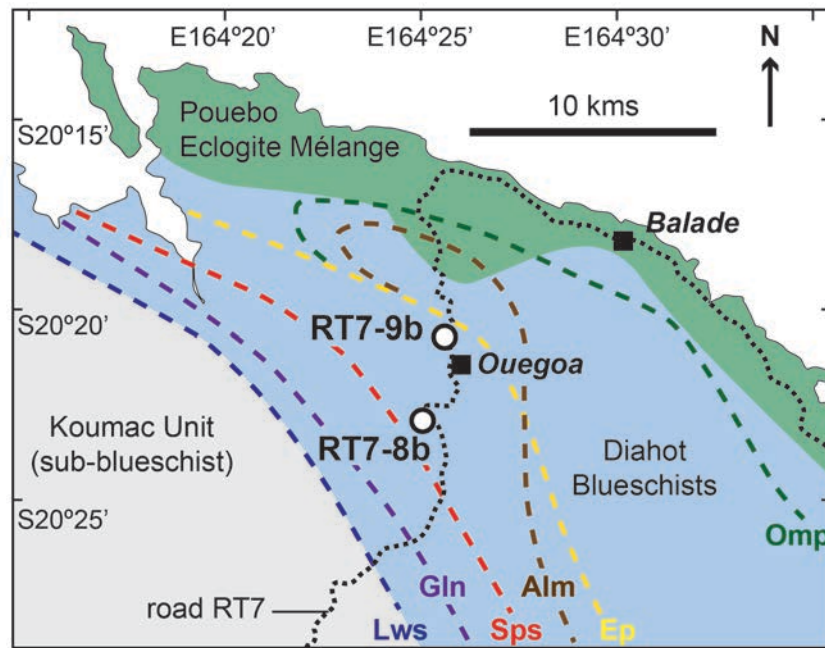


Figure A1. Map of north-eastern New Caledonia, with metamorphic isograds and approximate unit boundaries (adapted from Pirard and Spandler, 2017). The location of samples RT7-8b and RT7-9b are shown within the Diahot Blueschist unit. Lws = lawsonite, Gln = glaucophane, Sps = spessartine, Alm = almandine, Ep = epidote, Omp = omphacite.

Sample RT7-8b: Lawsonite Blueschist

Location: S 20° 22' 07.1"
E 164° 24' 41.3"

This sample is a fine-grained pelitic schist, with mm-scale interlayers of strongly crenulated quartz - mica - chlorite domains, and carbonate-cemented quartz - albite domains. Minor phases in both domains include blue amphibole (Fe-glaucophane), lawsonite, fine-grained Fe-oxides/hydroxides, and trace apatite and zircon. The grainsize rarely exceeds 200 μm , with the exception of some equant lawsonite porphyroblasts that can reach 300 μm in size, and occasional bladed blue amphiboles (up to 1 mm) that are oriented at a high angle to the foliation (Fig. A2). Apatite is often associated with quartz.

Sample RT7-8b corresponds to the ferroglauco-phane–lawsonite zone of Yokoyama et al. (1986) and Clarke et al. (1997). Based on the assemblage of the rock and location within the metamorphic sequence (Fig. A1), pressure-temperature conditions of metamorphism are

assigned to between 380 to 430 °C and between 1.0 to 1.4 GPa (Vitale Brovarone and Agard, 2013).

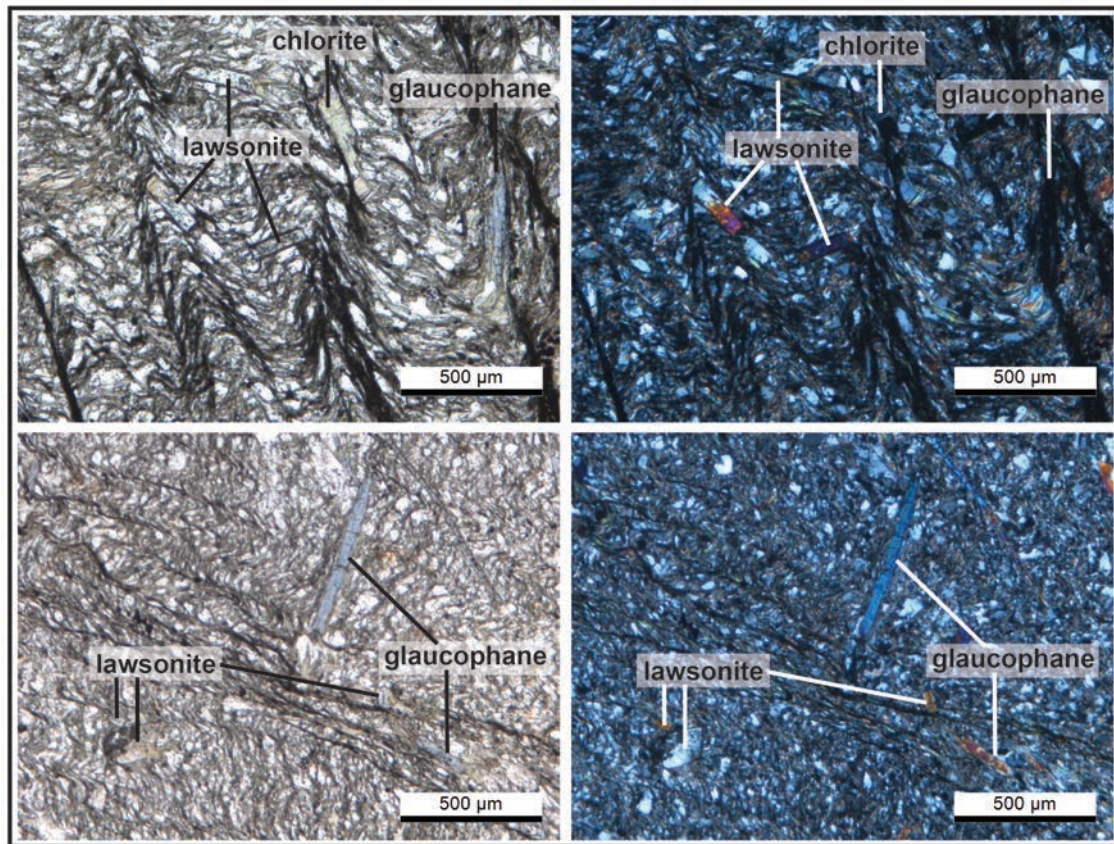


Figure A2. Plane-polarised (left side) and cross-polarised (right side) photomicrographs of sample RT7-8b. Relatively coarse euhedral lawsonite and bladed glaucophane porphyroblasts are distinguished from the fine quartz-mica matrix. The tight crenulation cleavage is evident in the top panels.

Sample RT7-9b: Lawsonite Blueschist (just below epidote-in isograd)

Location: S 20° 20' 29.9"
E 164° 25' 27.7"

This sample was collected from a quarry adjacent to route RT7, just north of Ouegoa village (Fig. A1). The sample is a dark carbonaceous schist consisting mostly of quartz, muscovite and glaucophane, with most minerals aligned with the prominent schistose foliation. Overall grainsize is coarser than RT7-8b, with bladed glaucophane reaching several mm in length some cases. Prismatic glaucophane and lawsonite can also be found in minor quartz-rich domains (Fig. A3). Other minor phases include apatite, titanite, fine graphite, and trace zircon.

Sample RT7-9b comes from the uppermost part of the lawsonite-ferroglaucophane zone, and pressure-temperature conditions are estimated to be between 470 and 520 °C and around 1.7 GPa (Vitale Brovarone and Agard, 2013).

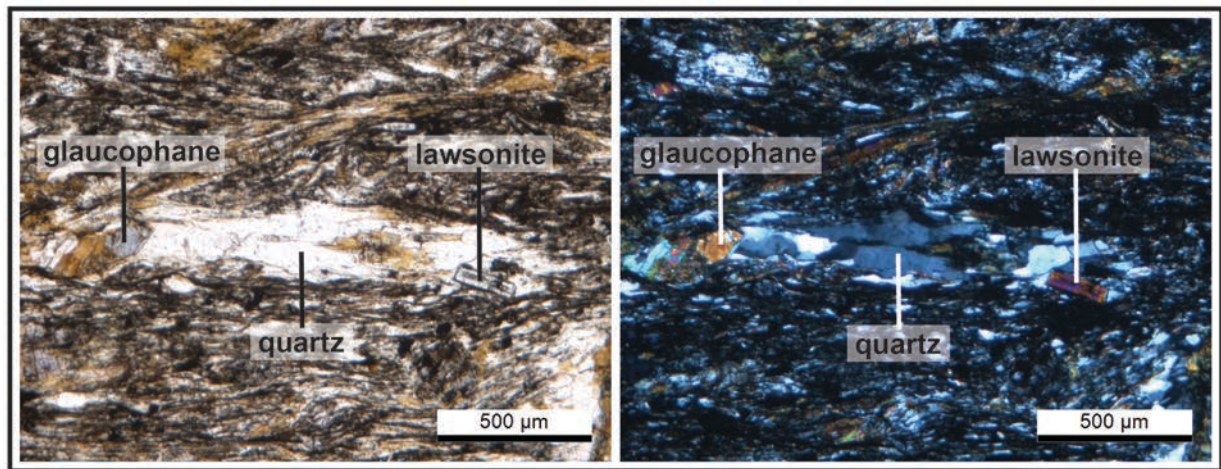


Figure A3. Plane-polarised (left side) and cross-polarised (right side) photomicrographs of sample RT7-9b. Prismatic lawsonite and glaucophane are evident within a quartz-rich domain within the schist.

LAGO DI CIGNANA

The UHP metamorphic rocks at Lago di Cignana (Val Tournanche, northern Italy) include serpentinites, metagabbros, metabasalts and pelagic metasediments (calcareous to pelitic) that collectively comprise a coherent slice of the Tethyan oceanic lithosphere that was subducted to depth of ca. 90 kms during the Eocene (Reineke, 1998; Frezzotti et al., 2011). Thermodynamic calculations, together with the presence of coesite and diamond relicts in some rocks, place peak eclogite-facies metamorphic conditions to be around 600 °C and between 2.8 and 3.2 GPa (Reinecke, 1998; Groppo et al., 2009; Frezzotti et al., 2011). These conditions were reached at between 40 and 44 Ma (Rubatto et al., 1998; Lapen et al., 2003), followed by rapid exhumation to greenschist-facies conditions by 38 Ma (Amato et al., 1999).

Good exposures of the metasedimentary rocks can be found along, and close to, the southern shoreline of the lake to the west of the dam wall (Fig. A4). The sequence is several tens of meters in thickness and consists of interlayered quartz-garnet-phengite schists of pelitic compositions, micaceous quartzites, and calc-schist (dolomite-calcite-garnet-phengite-quartz schist). Based on trace element and radiogenic isotope geochemistry, these sediments were likely derived from continental sources, and are expected to have undergone little chemical modification during subduction-related metamorphism (Mahlen et al., 2005; Bebout et al.,

2013). A diverse continental source is further confirmed by the presence of detrital zircons of variable age (160 Ma to >1.5 Ga; Rubatto et al., 1998).

We have chosen two quartzose metasedimentary rocks from this sequence for in situ Sm-Nd isotopic analysis. The diverse nature of the original detrital material comprising these metasediments supports our assertion that these rocks were likely to be isotopically heterogeneous at the grain scale prior to metamorphism. Our objective is to test whether Sm-Nd isotopic heterogeneity can be preserved during deep subduction-zone metamorphism.

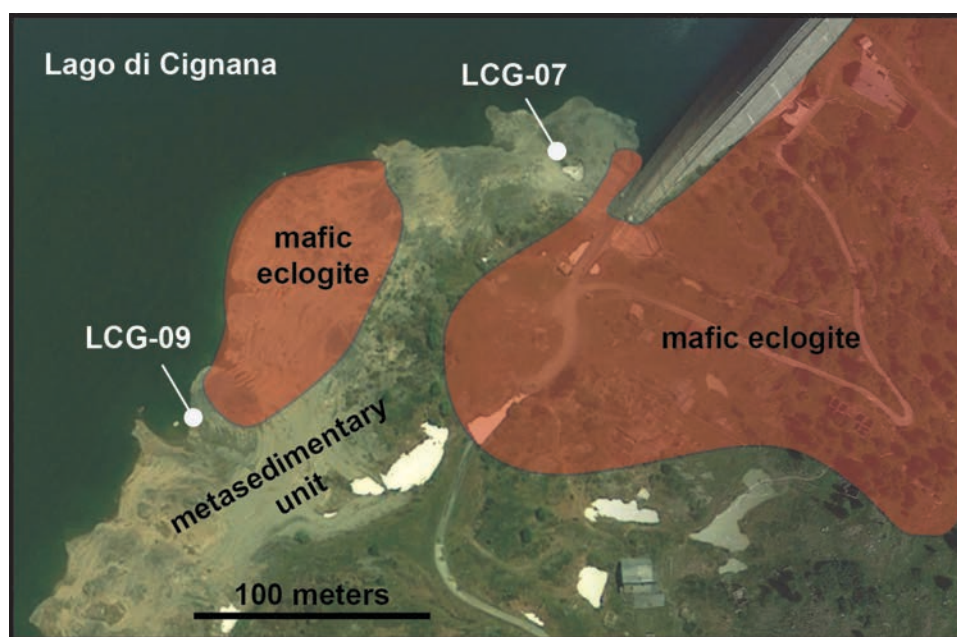


Figure A4. Aerial photo of the southern shore of Lago di Cignana, with the Dam wall visible in the top right of the photo. Most of the area consists of metagabbroic to metabasaltic eclogites (red fields) and eclogite-facies metasedimentary rocks (geological relationships from van der Klauw et al. (1997), and our own field observations). The locations of samples LCG-07 and LCG-09 are shown.

Sample LCG-07: eclogite-facies quartzose metasediment

Location: N 45° 52' 42.7"
 E 07° 35' 34.5"

LCG-07 is a medium-grain quartz-rich metasedimentary gneiss with alternating cm-thick green omphacite + amphibole bands and light-colored quartz + white mica bands. The eclogite-facies assemblage of the rock consists of quartz (~50%), omphacite (~10%), garnet (~10%), Na-Ca amphibole (5%), white mica (10%) and minor apatite, epidote, rutile, titanite

and calcite. Porphyroblastic garnets (Fig. A6a) are strongly zoned and can reach up to 5 mm in size. The eclogite-facies assemblage has undergone amphibolite-facies retrogression (Group 2 assemblage of van der Klaww et al., 1997), with partial recrystallization of omphacite and Na-Ca amphibole to actinolite, albite, epidote and titanite. The latter-formed epidote tends to be REE-poor, and can be found enveloping earlier formed REE-rich epidote (Fig. A5b). These REE-rich cores were targeted for in situ Sm-Nd isotope analysis. Likewise, apatite, which is often enclosed by quartz and appears unaffected by retrogression, was also analysed for Sm-Nd isotopes.

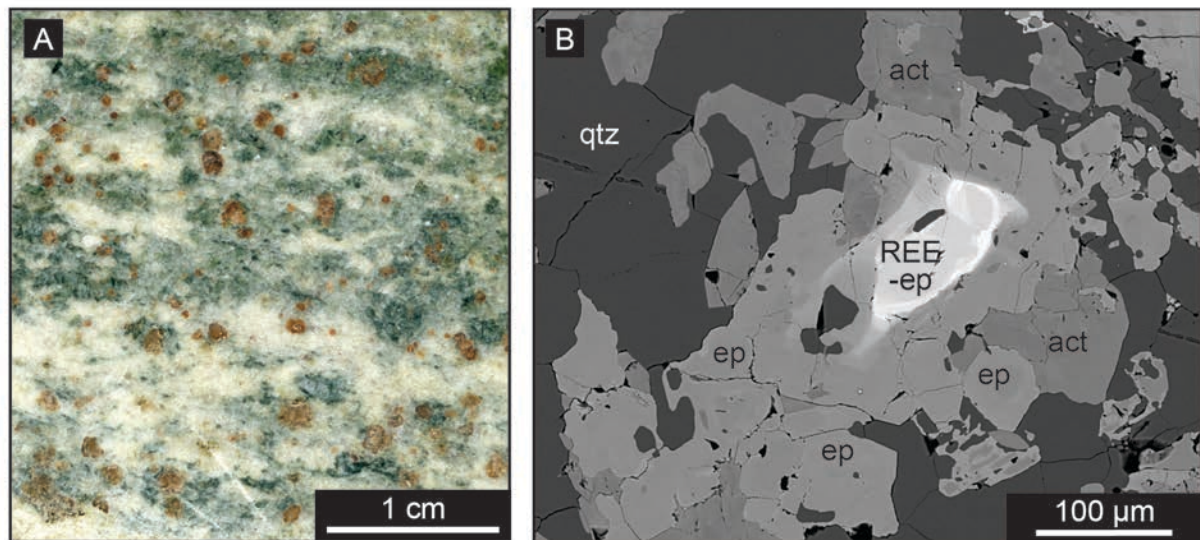


Figure A5. A. Photomicrograph of sample LCG-07 showing omphacite + Na-Ca amphibole + quartz domains (green), and white mica + quartz domains (white). Coarse euhedral garnet porphyroblasts (brown) are also evident. B. Backscattered electron image of REE-rich epidote (REE-ep) surrounded by REE-poor epidote (ep) and actinolite (act) formed during amphibolite-facies retrogression. qtz = quartz.

Sample LCG-09: eclogite-facies metamarlstone

Location: N 45° 52' 39.0"
E 07° 35' 26.6"

Sample LCG-09 is a light-coloured quartz – garnet – carbonate – mica schist that derives from a sequence of intercalated pelitic to carbonate-rich metasedimentary rocks exposed on the southern shoreline of Lago di Cignana (Fig. A4). Sample foliation is primarily defined by aligned phengite laths (1-2 mm in length) that make up approximately 20% of the rock. Garnet porphyroblasts (~15%), up to 5 mm in size are found throughout the rock (Fig.

A6a). Quartz (40%) and calcite+dolomite (15% combined) are the other major mineral components. Minor/trace minerals are titanite, apatite and epidote, all of which appear to be in textural equilibrium with the major mineral assemblage (Fig. A6 b, c). Retrogression is limited to minor chlorite replacement of garnet rims, and chlorite and sericite overprinting some phengite grains.

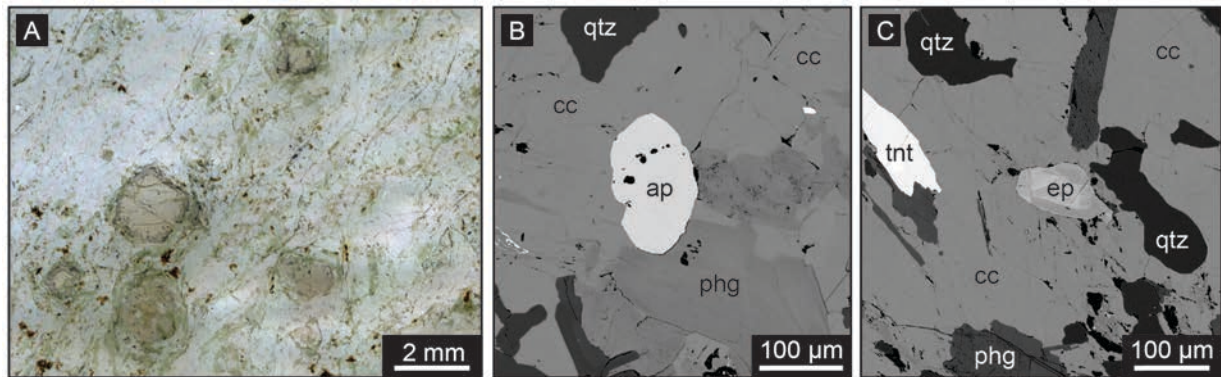


Figure A6. A. Photomicrograph of sample LCG-09 with coarse garnet (pink) porphyroblasts partially altered to chlorite on their rims, surrounded by a light-coloured matrix of phengite, carbonate (calcite + dolomite) and quartz. B. Backscattered electron image of an apatite (ap) grain surrounded by calcite (cc), phengite (phg) and quartz (qtz). C. Backscattered electron image of a zoned epidote (ep) grain surrounded by calcite (cc), phengite (phg), quartz (qtz), and titanite (tnt). Zoning in the epidote grain largely reflects varying REE contents.

DORA MAIRA

The Dora Maira Massif is one of three Internal Crystalline Massifs of the Western Alps (Italy). These massifs consist of pre-alpine continental basement rocks that were subject to HP to UHP metamorphism during Alpine orogeny. In the southern portion of Dora Maira are the UHP metagranitic to metasedimentary rocks of the Brossasco-Isasca Unit (BIU; Compagnoni et al., 1994). From this unit was one of the first descriptions of coesite from metamorphosed crustal rocks (Chopin, 1984). These rocks experienced metamorphism during both Variscan and Alpine orogenic events. Peak conditions of Alpine metamorphism of 730 °C and approx. 4.0 GPa (Hermann, 2003; Groppo et al., 2007) for the BIU were reached at approximately 35 Ma (Gebauer et al., 1997).

In this study we have analysed a coarse quartz-garnet-mica schist sample (DM3) that comes from poorly exposed outcrop approximately 1 km south of the town of Isasca. The precise location of the sample site was not recorded during sampling. The sample is pelitic in composition and consists of quartz (~35%) phengite (~30%), kyanite (~10%), garnet (20%),

rutile (1%) and accessory monazite and zircon. The rock is deficient in CaO and Na₂O and hence lacks pyroxene or amphibole. Garnet porphyroblasts may reach up to 5 mm (Fig. A7a) and are often inclusion rich, with radial fractures in garnet mantling the inclusions (Fig. A7b, c). Many of the inclusions are polycrystalline quartz with textures that are characteristic of quartz after coesite (Chopin, 1984). Monazite is the only REE-rich phase in the rock, and occurs entirely within phengite as clusters of fine (< 100 µm) grains (Fig. A8).

The rock is free of metamorphic retrogression, but has suffered alteration due to surface weathering, as manifest by Fe-Al oxide/hydroxide alteration of garnet along grain boundaries and fractures (Fig. A7), and limited sericite replacement of phengite.

Estimates on the peak metamorphic conditions for sample DM3 can be gained from the mineral compositions and assemblages. The former presence of coesite (as polycrystalline quartz inclusions in garnet; Fig. A7c) indicate metamorphism under UHP conditions, as documented in other rocks of the Brossasco-Isasca Unit (Chopin, 1984; Compagnoni et al., 1994; Hermann, 2003). Zirconium contents of rutile are between 110 and 150 ppm, which give a peak metamorphic temperature (under UHP conditions) of 660 to 700 °C, using the Zr-in-rutile thermometer of Tomkins et al. (2007). Phengite compositions (including those that host the monazite) have Si and Ti atoms-per-formula-unit of up to 3.5, and between 0.01 and 0.25, respectively. These compositions are consistent with metamorphic conditions of 3.5 to 4.0 GPa at temperatures between 660 and 700 °C, according to the phase compositional relationships of Auzanneau et al. (2010) and Hermann (2003). Collectively, we consider the peak metamorphic conditions of the DM3 to be similar to other parts of the BIU as around 700 °C and 4.0 GPa.

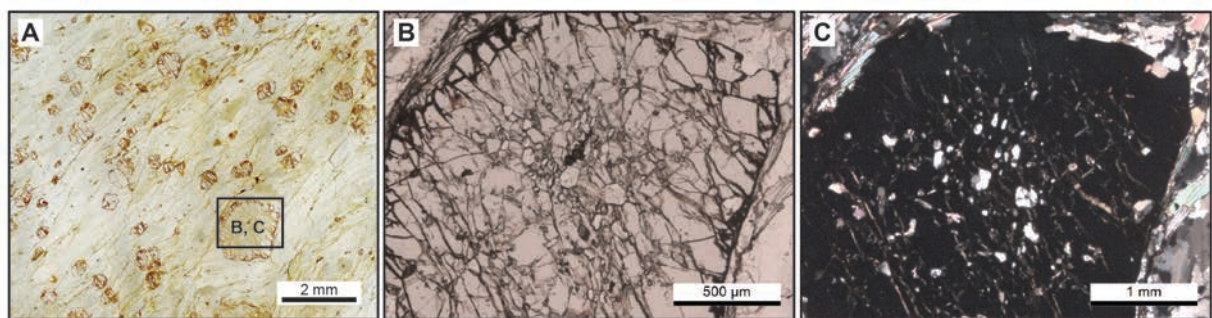


Figure A7. A. Photomicrograph of sample DM3 with coarse almandine garnet porphyroblasts (with thin weathering rinds) within a foliated matrix of phengite and quartz. B. Plane-polarised light photomicrograph of the coarse garnet porphyroblast with abundant inclusions and fractures. C. Cross-polarised light photomicrograph of (B), with the multiphase nature of the quartz inclusions evident. This texture is characteristic of quartz inclusions after coesite.

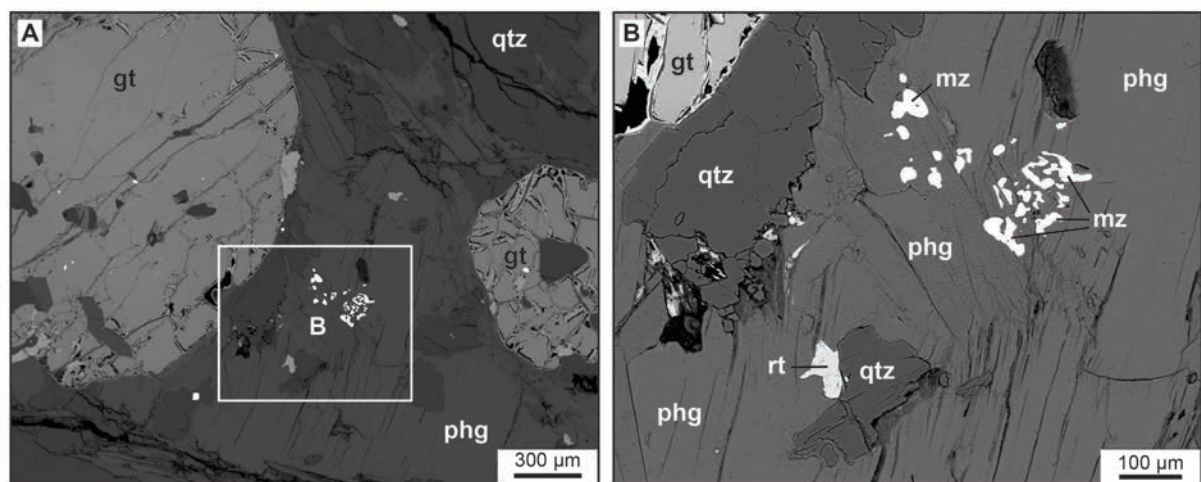


Figure A8. A. Backscattered electron image of sample DM3 with inclusion-rich garnet (gt), quartz (qtz) and phengite (phg). B. Inset of (A) showing a cluster of fine monazite (mz) grains within phengite. Rutile (rt) also occurs in phengite. The composition of phengite and coexisting rutile indicate peak metamorphism under UHP conditions (see text).

Appendix DR2

- *Analytical techniques
- *Bulk rock data
- *Mineral trace element data

Appendix DR3

- * Techniques for in situ Sm-Nd isotope analysis of minerals
- * Isotope data

References:

- Auzanneau, E., Schmidt, M.W., Vielzeuf, D., and Connolly, J.D., 2010, Titanium in phengite: a geobarometer for high temperature eclogites: *Contributions to Mineralogy and Petrology*, v. 159, p. 1-24.
- Aitchison, J.C., Clarke, G.L., Meffre, S., and Cluzel, D., 1995, Eocene arc-continent collision in New Caledonia and implications for regional southwest Pacific tectonic evolution: *Geology*, v. 23, p. 161-164.
- Amato, J.M., Johnson, C.M., Baumgartner, L.P., and Beard, B.L., 1999, Rapid exhumation of the Zermatt-Saas ophiolite deduced from high-precision Sm-Nd and Rb-Sr geochronology: *Earth and Planetary Science Letters*, v. 171, p. 425-438.
- Baldwin, S.L., Rawling, T., and Fitzgerald, P.G., 2007, Thermochronology of the New Caledonian high-pressure terrane: Implications for middle Tertiary plate boundary processes in the southwest Pacific: *Geological Society of America Special Papers*, v. 419, p. 117-134.
- Bebout, G.E., Agard, P., Kobayashi, K., Moriguti, T., and Nakamura, E., 2013, Devolatilization history and trace element mobility in deeply subducted sedimentary rocks: Evidence from Western Alps HP/UHP suites: *Chemical Geology*, v. 342, p. 1-20.
- Chopin, C., 1984, Coesite and pure pyrope in high-grade blueschists of the Western Alps: a first record and some consequences: *Contributions to Mineralogy and Petrology*, v. 86, p. 107-118.
- Clarke, G.L., Aitchison, J.C., and Cluzel, D., 1997, Eclogites and blueschists of the Pam Peninsula, NE New Caledonia; a reappraisal: *Journal of Petrology*, v. 38, p. 843-876.
- Cluzel, D., Maurizot, P., Collot, J., and Sevin, B., 2012, An outline of the geology of New Caledonia; from Permian-Mesozoic Southeast Gondwanaland active margin to Cenozoic obduction and supergene evolution: *Episodes*, v. 35, p. 72-86.
- Compagnoni, R., Hirajima, T., Turello, R., and Castelli, D., 1994, The Brossasco-Isasca Unit. In High pressure metamorphism in the Western Alps. Guide-book to the field excursion B1 16th General Meeting of the International Mineralogical Association, Pisa pp. 10-15.
- Fitzherbert, J.A., Clarke, G.L., and Powell, R., 2005, Preferential retrogression of high-P metasediments and the preservation of blueschist to eclogite facies metabasite during exhumation, Diahot terrane, NE New Caledonia: *Lithos*, v. 83, p. 67-96.

- Frezzotti, M.L., Selverstone, J., Sharp, Z.D., and Compagnoni, R., 2011, Carbonate dissolution during subduction revealed by diamond-bearing rocks from the Alps: *Nature Geoscience*, v. 4, p. 703-706.
- Gebauer, D.H.P.S., Schertl, H.P., Brix, M., and Schreyer, W., 1997, 35 Ma old ultrahigh-pressure metamorphism and evidence for very rapid exhumation in the Dora Maira Massif, Western Alps: *Lithos*, v. 41, p. 5-24
- Groppo, C., Lombardo, B., Castelli, D., and Compagnoni, R., 2007, Exhumation history of the UHPM Brossasco-Isasca Unit, Dora-Maira Massif, as inferred from a phengite-amphibole eclogite: *International Geology Review*, v. 49, p. 142-168.
- Groppo, C., Beltrando, M., and Compagnoni, R., 2009, The P–T path of the ultra-high pressure Lago di Cignana and adjoining high-pressure meta-ophiolitic units: insights into the evolution of the subducting Tethyan slab: *Journal of Metamorphic Geology*, v. 27, p. 207-231.
- Hermann, J., 2003, Experimental evidence for diamond-facies metamorphism in the Dora-Maira massif: *Lithos*, v. 70, p. 163-182.
- Lapen, T.J., Johnson, C.M., Baumgartner, L.P., Mahlen, N.J., Beard, B.L., and Amato, J.M., 2003, Burial rates during prograde metamorphism of an ultra-high-pressure terrane: an example from Lago di Cignana, western Alps, Italy: *Earth and Planetary Science Letters*, v. 215, p. 57-72.
- Mahlen, N.J., Johnson, C.M., Baumgartner, L.P., and Beard, B.L., 2005, Provenance of Jurassic Tethyan sediments in the HP/UHP Zermatt-Saas ophiolite, western Alps: *Geological Society of America Bulletin*, v. 117, p. 530-544.
- Pirard C., and Spandler, C., 2017, The zircon record of high-pressure metasedimentary rocks of New Caledonia: Implications for regional tectonics of the south-west Pacific: *Gondwana Research*, v. 46, p. 79-94.
- Rawling, T.J., and Lister, G.S., 2002, Large-scale structure of the eclogite-blueschist belt of New Caledonia: *Journal of Structural Geology*, v. 24, p. 1239-1258.
- Reinecke, T., 1998, Prograde high-to ultrahigh-pressure metamorphism and exhumation of oceanic sediments at Lago di Cignana, Zermatt-Saas Zone, western Alps: *Lithos*, v. 42, p. 147-189.
- Rubatto, D., Gebauer, D., and Fanning, M., 1998, Jurassic formation and Eocene subduction of the Zermatt–Saas-Fee ophiolites: implications for the geodynamic evolution of the Central and Western Alps: *Contributions to Mineralogy and Petrology*, v. 132, p. 269-287.

- Spandler, C.J., Hermann, J., Arculus, R.J., and Mavrogenes, J.A., 2004, Geochemical heterogeneity and element mobility in deeply subducted oceanic crust; insights from high-pressure mafic rocks from New Caledonia: *Chemical Geology*, v. 206, p. 21-42.
- Spandler, C.J., Rubatto, D., and Hermann, J., 2005, Late Cretaceous-Tertiary tectonics of the southwest Pacific; insights from U-Pb SHRIMP dating of eclogite-facies rocks from New Caledonia: *Tectonics*, v. 24, TC3003.
- Spandler, C., Hermann, J., Faure, K., Mavrogenes, J.A. and Arculus, R.J., 2008, The importance of talc and chlorite “hybrid” rocks for volatile recycling through subduction zones; evidence from the high-pressure subduction mélange of New Caledonia: *Contributions to Mineralogy and Petrology*, v. 155, p. 181-198.
- Taetz, S., John, T., Bröcker, M., and Spandler, C., 2016, Fluid–rock interaction and evolution of a high-pressure/low-temperature vein system in eclogite from New Caledonia: insights into intraslab fluid flow processes: *Contributions to Mineralogy and Petrology*, v. 171, p. 90.
- Tomkins, H.S., Powell, R., Ellis, D.J., 2007, The pressure dependence of the zirconium-in-rutile thermometer: *Journal of Metamorphic Geology*, v. 25, p. 703-713.
- van der Klaww, S.N.G.C., Reinecke, T., Stöckhert, B., 1997, Exhumation of ultrahigh-pressure metamorphic oceanic crust from Lago di Cignana, Piemontese zone, western Alps: the structural record in metabasites: *Lithos*, v. 41, p. 79-102.
- Vitale Brovarone, A., Agard, P. 2013, True metamorphic isograds or tectonically sliced metamorphic sequence? New high-spatial resolution petrological data for the New Caledonia case study: *Contributions to Mineralogy and Petrology*, v. 166, p. 451-469.
- Yokoyama, K., Brothers, R.N., Black, P.M., 1986, Regional eclogite facies in the high-pressure metamorphic belt of New Caledonia: *Geological Society of America Memoirs*, v. 164, p. 407-424.