



# Fast intraslab fluid-flow events linked to pulses of high pore fluid pressure at the subducted plate interface



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## ABSTRACT

A better understanding of the subduction zone fluid cycle and its chemical–mechanical feedback requires in-depth knowledge about how fluids flow within and out of descending slabs. Relicts of fluid-flow systems in exhumed rocks of fossil subduction zones allow for identification of the general relationships between dehydration reactions, fluid pathway formation, the dimensions and timescales of distinct fluid flow events; all of which are required for quantitative models for fluid-induced subduction zone processes. Two types of garnet–quartz–phengite veins can be distinguished in an eclogite-facies mélange block from the Pouébo Eclogite Mélange, New Caledonia. These veins record synmetamorphic internal fluid release by mineral breakdown reactions (type I veins), and infiltration of an external fluid (type II veins) with the associated formation of a reaction selvage. The dehydration and fluid migration documented by the type I veins likely occurred on a timescale of  $10^5$ – $10^6$  years, based on average subduction rates and metamorphic conditions required for mineral dehydration and fluid flow. The timeframe of fluid–rock interaction between the external fluid and the wall-rock of the type II veins is quantified using a continuous bulk-rock Li-diffusion profile perpendicular to a vein and its metasomatic selvage. Differences in Li concentration between the internal and external fluid reservoirs resulted in a distinct diffusion profile (decreasing Li concentration and increasing  $\delta^7\text{Li}$ ) as the reaction front propagated into the host rock. Li-chronometric constraints indicate that the timescales of fluid–rock interaction associated with type II vein formation are on the order of 1 to 4 months ( $0.150^{+0.14}_{-0.08}$  years). The short-lived, pulse-like character of this process is consistent with the notion that fluid flow caused by oceanic crust dehydration at the blueschist-to-eclogite transition contributes to or even dominates episodic pore fluid pressure increases at the plate interface, which in turn, may trigger slip events reported from many subduction zones.

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## 1. Introduction

Element cycling at subduction zones controls the global geochemical budget of many elements and is a crucial process for the evolution of Earth's mantle–crust–atmosphere system. As subducting plates heat up during their passage into the deeper mantle, hydrous minerals within the different rocks of the subducted slab become progressively unstable, eventually break down, and release water. The most prominent dehydration reactions are related to the transformation of hydrous amphiboles and chlorite to anhydrous omphacite and garnet during eclogitisation of the subducting oceanic crust (e.g. Gao and Klemd, 2001;

John et al., 2012; Peacock, 1993). Expelled fluids migrate via channelized flow through the subducted slab and mantle wedge (e.g. Ague, 2011; Angiboust et al., 2014; John et al., 2008, 2012; Plümpner et al., 2017; Scambelluri and Philippot, 2001; Taetz et al., 2016). Field observations document that these fluids may react with their wall rocks, thereby mobilising and transporting soluble elements (e.g. LILE, LREE) (Bebout, 2007; Gao et al., 2007; Herms et al., 2012; John et al., 2004, 2012), and thereby induce the formation of melts in the mantle wedge with distinct chemical signatures (e.g. John et al., 2004; Vrijmoed et al., 2013).

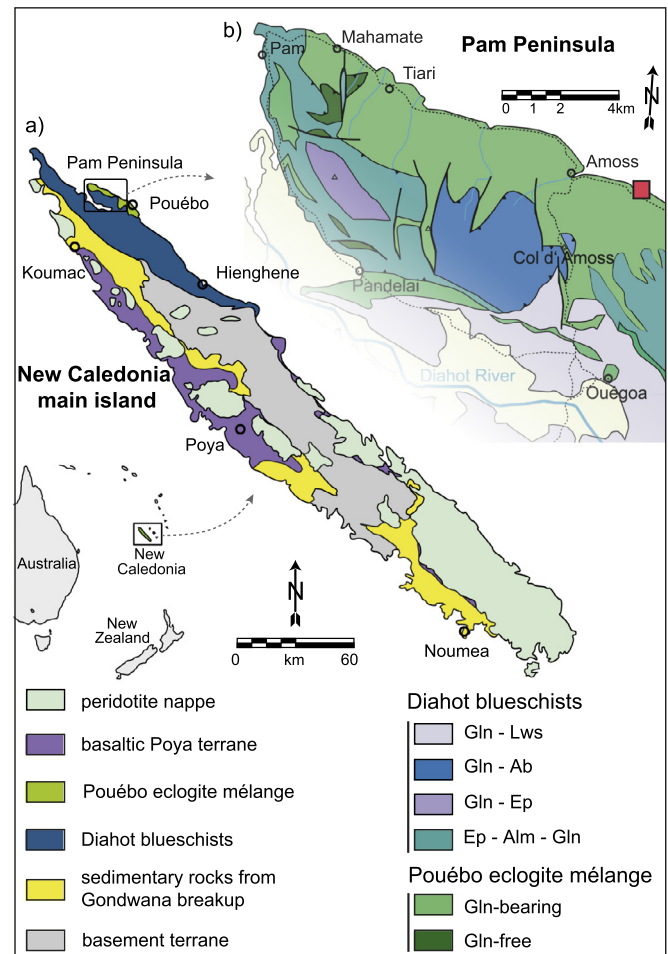
Various seismic to nonseismic slip phenomena (e.g. megathrust earthquakes, episodic tremor and slip events, silent earthquakes, creep) occurring at the plate interface have been linked to high pore fluid pressure or even sudden increase of the local pore fluid pressure regime (e.g. Audet et al., 2009; Beroza and Ide, 2011; Fagereng and Diener, 2011; Moreno et al., 2014;

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Schurr et al., 2014). The required rise of fluid pressure is probably caused by dehydration reactions within the descending slab (e.g. Dragovic et al., 2015; Fagereng and Diener, 2011; Moreno et al., 2014; Schurr et al., 2014). Several studies suggest that the periodicity of some of these events is controlled by cyclic changes in pore fluid pressure, with slip occurring when a sufficient amount of fluid had been accumulated (e.g. Frank et al., 2015; Gomberg et al., 2010). The increased permeability induced by the slip event reduces the elevated pore pressure (Skarbek and Rempel, 2016), but owing to continuing fluid production within the descending slab, the system recovers (Plümper et al., 2017; Taetz et al., 2016) until again a critical fluid pressure is reached.

Key towards a better understanding of the subduction zone fluid cycle and its chemical and mechanical feedback along the plate interface is obtaining in-depth understanding of how fluids flow within and out of the descending slab. Developing reliable quantitative models of fluid-mediated mass transfer in a subducting slab requires quantifying the general relationships between mineral reactions, fluid flow and element mobilization during fluid–rock interaction. (e.g. Angiboust et al., 2014; Bebout, 2007; Gao et al., 2007; John et al., 2004; Spandler et al., 2011; Taetz et al., 2016). The dimensions and timescales of distinct fluid flow events and the physico-chemical processes triggered by fluid flow are crucial parameters of such models. However, direct investigation of dehydration-related fluid flow in subducting slabs is impossible and, owing to the dm- to m-sized dimensions of the flow structures (e.g. Gao et al., 2007; Gao and Klemd, 2001; Herms et al., 2012; John et al., 2008, 2012; Spandler and Hermann, 2006), are not detectable in-situ by geophysical methods. Consequently, samples exhumed long after (i.e. millions of years) fluid–rock interaction occurred provide the only direct observational evidence. But determining the duration of fast processes that have happened in the geologic past is a difficult task. Isotopic chronometers commonly used to date the high-pressure rocks (e.g. Lu–Hf, Sm–Nd, Ar–Ar, Rb–Sr for absolute ages) are too imprecise to resolve short-duration events of several thousand years or less (e.g. Ague and Baxter, 2007; Bons, 2001; Camacho et al., 2005; John et al., 2012). Determining the relative timescales of diffusive processes that affect fast diffusing elements, however, is one possible means to quantify the timing of such processes (e.g. John et al., 2012; Watson and Baxter, 2007). In fluid flow related structures diffusion may occur on the cm- to outcrop-scale between pristine wall rock and the fluid conduit, as documented in the formation of reaction selvages (e.g. Ague, 2003; Beinlich et al., 2010; Penniston-Dorland and Ferry, 2008). In such reaction zones, mineral reaction at the fluid–rock interface is considered to proceed faster than the rate of fluid transport (e.g. Jamtveit et al., 2000; John et al., 2012). Consequently, in these fluid dominated systems, element transport within the reaction selvage is primarily controlled by bulk diffusion (e.g. Watson and Baxter, 2007). Lithium-chronometry based on bulk-diffusion modelling is a tool that allows the determination of the timescales of such fast and relatively cool (<700 °C) geological processes (e.g. John et al., 2012; Teng et al., 2006; Watson and Baxter, 2007). Lithium is a trace element in both fluid and solid phases, and is not strongly partitioned into any metamorphic phases. Nevertheless, Li can undergo significant kinetic fractionation between the two stable isotopes  $^6\text{Li}$  and  $^7\text{Li}$ , resulting in faster diffusion of  $^6\text{Li}$  compared to  $^7\text{Li}$  (e.g. Richter et al., 2006). This process leads to isotopic variations that are easily resolvable using modern analytical techniques (e.g. John et al., 2012; Penniston-Dorland et al., 2010; Teng et al., 2006). Therefore, diffusion modelling based on Li has the advantage that both concentration profiles and isotope ratio profiles can be used, which provides additional measures of consistency and robustness to the models.



**Fig. 1.** a) Simplified geological map of New Caledonia (after Aitchison et al., 1995); b) close-up of the Pam Peninsula (after Clarke et al., 1997) with mineral distribution patterns. The position of the sampling site is indicated by the red square. (Gln = glaucophane; Lws = lawsonite; Ab = albite; Ep = epidote; Alm = almandine).

The high-pressure/low-temperature (HP/LT) metamorphic rocks of the Pouébo Eclogite Mélange in New Caledonia provide an excellent opportunity to study the fluid flux in a subduction zone setting. The focus of this study is on the fluid dynamics recorded by two types of garnet–quartz–phengite veins that cross-cut eclogite facies mélange blocks from this occurrence (Spandler and Hermann, 2006; Taetz et al., 2016). These veins document both internal fluid release by mineral breakdown reactions and infiltration of external fluids (Spandler and Hermann, 2006; Taetz et al., 2016). Taetz et al. (2016) investigated the main petrological, geochemical and geochronological characteristics of the rocks cut by the veins and developed a conceptual model for vein formation. Here, we present results of Li chronometry based on bulk diffusion modelling that provide quantitative constraints on the duration of a distinct vein-forming fluid flow event.

## 2. Geological setting

The metamorphic HP/LT ophiolite complex located in the NE part of the main island of New Caledonia (Fig. 1) is characterized by a regular pattern of mineral isograds. The prograde regional  $P$ – $T$  gradient ranges from 0.3 GPa, 250 °C in the SW to ca. 1.9–2.4 GPa, 500–650 °C in the NE (Carson et al., 1999; Clarke et al., 1997; e.g. Vitale Brovarone and Agard, 2013). The highest grade eclogite-facies rocks occur in the Pouébo Eclogite Mélange (PEM) (e.g. Carson et al., 1999; Clarke et al., 1997; Spandler et al., 2005),

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