Transfer of melts in the sub-arc mantle: Insights from high-pressure experiments and from the New Caledonia ophiolite.

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All of the work presented in this thesis is my own, except where otherwise acknowledged. Some of the ideas presented have benefited from discussions with my supervisors and other colleagues, but all interpretations and conclusions are my own.

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Transfer of melts in the sub-arc mantle:
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Abstract

The transfer of fluids produced by the dehydration of a subducted oceanic slab through the mantle wedge remains one of the least constrained segments for the element recycling in the “subduction factory”. In this thesis, the element transfer in the mantle wedge is investigated using high-pressure experiments and observations from the ophiolitic nappe of the Massif du Sud in New Caledonia.

High-pressure experiments were aimed to study the interaction between slab melts and the sub-arc mantle at depth of ~100 km in a range of P-T conditions which are representative of the mantle wedge above the subducted slab. Experiments have shown that porous reactive flow induces the formation of large amounts of phlogopite and amphibole in the pressure range of 25 to 45 kbar for 800 to 1000°C. The formation of these hydrous phases leads to a strong depletion of the residual fluid in LREE (sequestrated in amphibole) and LILE (sequestrated in phlogopite). The wet solidus obtained in the experiments is 975°C at 35 kbar. This new set of data provides constraints on the composition and the melting conditions of slab-metasomatised peridotite and highlights the major role that alkali-rich amphibole (magnesiokatophorite) play in the sub-arc mantle and the particular composition of melt produced by metasomatised peridotite.

Experimental reproduction of focused flow in the mantle wedge shows that orthopyroxenite walls form at the interface between slab melts and olivine. Therefore, there is a very limited interaction with the surrounding peridotite. The trace element composition of the slab melt is only slightly modified in this
process. Therefore, the transfer of slab melt by focused flow to the locus of partial melting in the mantle wedge provides a much more efficient way to conserve the slab signature than porous flow.

The New Caledonia ultramafic ophiolite provides a natural laboratory for the interactions between arc magmas and the upper mantle. This thesis gives the first comprehensive overview of the Massif du Sud ophiolite on the basis of petrological and geochemical data. The Massif du Sud is one of the most depleted and the largest mantle ophiolite on Earth. This thesis shows that the preserved 3000 m thick mantle section is related to an arc environment that develops on a previous spreading ridge.

A suite of rocks involving dunite channels, pyroxenite channels, pyroxenite dykes and gabbro dykes present in the Massif du Sud show the evolution of hydrous and silica-rich melts transferred by focused porous flow. Melts that are transported through these channels and dykes are feeding the bottom part of an arc crust. The observation of such melt evolution at sub-Moho levels provides critical information in solving the arc paradox which necessitates large amount of pyroxenite cumulate in the mantle to explain the bulk composition of arc crust.

A late generation of pyroxenite and amphibole dykes has been connected to the emplacement of large felsic intrusions at the crust-mantle boundary. U-Pb dating of separated zircons from these intrusions and associated dykes provides Eocene ages confirming that this series of rocks are a pre-obductive feature of the Massif du Sud. These rocks represent a late fore-arc igneous activity and provide new information on melt-mantle interaction and the composition of melts in a colder part of the mantle wedge. The relative timing of events recorded in the New Caledonia ophiolite also imposes new constraints on the geodynamics of the South West Pacific from the middle Cretaceous to recent times.
Caractérisation du transfert de magma dans le manteau de sous-arc au moyen de la pétrologie expérimentale à haute pression et de l’ophiolite de Nouvelle Calédonie.

Résumé

Le transfert de fluides produit par la déshydratation de la plaque océanique subductée dans le coin mantellique reste l'une des parties les moins contrainte dans le recyclage d'éléments de la « subduction factory ». Dans cette thèse, le transfert d'éléments dans le coin mantellique est étudié au travers d'expériences à haute pression et d'observations faites dans la nappe ophiolitique du Massif du Sud en Nouvelle Calédonie.

Les expériences à haute pression ont pour but d'étudier les interactions entre les magmas issus de la croute océanique subductée et le manteau de sous-arc à une profondeur de ~100 km, dans un champ de conditions P-T qui est représentatif du coin mantellique au dessus d'une plaque océanique subductée. Les expériences ont montré que le transfert par flux en utilisant la porosité du manteau produit une quantité importante de phlogopite et d'amphibole dans l'intervalle de pression de 25 à 45 kbar pour des températures de 800 à 1000°C. La cristallisation de ces phases hydratées entraîne un appauvrissement important du fluide résiduel en LREE (séquestrée par l'amphibole) et LILE (séquestré par la phlogopite). Le solidus hydraté obtenu pour ces expériences est de 975°C pour 35 kbar. Ces nouvelles données imposent des contraintes additionnelles sur la composition et les conditions de fusion d'une péridotite métasomatisée par les fluides et soulignent le rôle majeur que joue les amphiboles alcalines (magnesiokatophorite) dans le manteau de sous-arc et en particulier la composition des liquides produits par les péridotites métasomatisées.
La reproduction expérimentale d’un écoulement canalisé dans le coin mantellique montre que des épontes d’orthopyroxénite se forment à l’interface entre le liquide provenant de la plaque océanique et l’olivine. Il y a donc une interaction très limitée avec la roche ultramafique hôte. La teneur en éléments en traces dans le liquide présent dans les conduits ne varie que de manière insignifiante lors de ce processus. Il semble donc que le transfert de magma au travers de chenaux quittant la croute océanique subductée pour atteindre la région de fusion partielle dans le coin mantellique soit beaucoup plus efficace pour conserver la signature crustale que lorsque ce transfert se fait par percolation.

L’ophiolite ultramafique de Nouvelle Calédonie fourni un laboratoire naturel où les interactions entre des magmas d’arc et le manteau supérieur peuvent être observées. Ce travail fourni le premier aperçu général de l’ophiolite du Massif du Sud sur bases de données pétrologiques et géochimiques. Le Massif du Sud est la plus grande des ophiolites mantelliques sur Terre. C’est aussi l’un des massif ultramafique les plus appauvri. Cette thèse donne une description détaillée de plus de 3000 m de séquence mantellique ainsi que la zone de transition la surmontant et montre comment cette ophiolite est liée a un environnement d’arc qui s’est développé sur une croute océanique plus ancienne.

Une suite de roches comprenant des chenaux dunitiques et pyroxènitiques ainsi que des dykes de pyroxènites et de gabbros ont été observés dans le Massif du Sud. Ces veines sont le témoin de l’évolution d’un liquide silicaté hydraté qui est transféré au travers de conduits poreux pour former la croute océanique. Le magma est transporté aux travers de ces conduits pour alimenter la partie inférieure de l’arc volcanique. L’observation de l’évolution de liquide silicaté à un niveau sub-Moho donne de nouvelles informations essentielles pour résoudre le paradoxe de l’arc qui nécessite de grande quantité de cumulats de pyroxènes pour expliquer la composition globale de la croute d’un arc.
Une génération tardive de pyroxènites et de dykes d’amphibole est liée à la mise en place de larges intrusions felsiques au niveau de la transition manteau-croute. La datation U-Pb sur des zircons séparés de ces intrusions ainsi que des dykes associés donne un âge Eocène qui confirme que ces roches ont été formées avant l’obduction du Massif du Sud. Ces roches représentent une activité magmatique tardive d’avant-arc et fourni de nouvelles informations sur les interactions entre magma et manteau et sur la composition de ces magmas dans des régions plus froides du coin mantellique. La datation relative des différents événements enregistrés dans l’ophiolite de Nouvelle Calédonie impose également de nouvelles contraintes sur les reconstructions géodynamiques du Pacifique du Crétacé moyen à nos jours.
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