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Review Article

# Tectonic significance of serpentinites

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ABSTRACT

At plate boundaries, where deformation is localized along centimetre- to kilometre-scale shear zones, the influence of serpentinite on tectonic processes is linked to its unique rheological properties. In this paper we review the physical properties of serpentinites and their role in tectonic processes. At the ocean–continent transition, serpentinization weakens the upper mantle layer, promoting strain localization and allowing the normal faults in the distal margin to root at low angle. Similarly, at slow to ultra-slow spreading ridges, serpentinite is potentially very abundant at the seafloor and locally associated with domal structures. Extensional deformation is localized in a ~100 m thick shear zone at the footwall of detachment zones dominated by serpentine derived minerals. Within subduction zone, the depth of decoupling between the mantle wedge and the subducting slab corresponds to the stability depth of serpentine weak mineral. Dehydration of serpentine has also been hypothesized to play an important role in the origin of double seismic zones, however the exact mechanism through which dehydration promotes seismicity remains a matter of debate. During exhumation of high-pressure or ultrahigh-pressure rocks, the opposite trajectories of exhumation and subduction require a decoupling zone within the subducting slab. A serpentinized layer has the potential to become a decoupling zone between the oceanic crust and underlying lithosphere. The buoyancy of serpentinite also likely contributes to eclogite exhumation. Finally, along major strike-slip faults, serpentinites have been associated with fault creep, as well as low fault strength. The presence of serpentinite blocks along creeping segments of active faults worldwide is therefore likely to originate from fluids deriving from the progressive dehydration of the mantle wedge that move such bodies upward.



**Contents**



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## 1. Introduction

Plate tectonics is driven by tectonic forces originating either from mantle convection, slab pull and ridge push. This results in a combination of ductile flow and frictional resistance in fault zones. Lithospheric thickness is variable, ranging from 5 to 100 km in oceanic domains and up to 350 km in cratonic ones. It is assumed to be stabilized against the convective upper mantle as its temperature (~1250 °C) is just below the melting point of peridotite, dominated by the very high strength constituent olivine mineral (Kohlstedt et al., 1995). At plate tectonic boundaries, the lithosphere is deformed and strain localization occurs at kilometre scale suggesting that the strength of the lithospheric mantle is locally reduced. Whatever the tectonic setting (from ocean-floor to subduction zones), the mode of lithospheric deformation is strongly controlled by its rheological layering, which depends on several parameters: deviatoric stress, geothermal gradient, age and nature of the lithosphere, and occurrence of fluids (Burov and Watts, 2006; Huismans and Beaumont, 2012; Mouthereau et al., 2013). Within the upper mantle, between 1250 and 800 °C, several weakening mechanisms have been suggested, as trace amounts of water in olivine will result in significantly lower creep strength (Karato et al., 1986) or a weakening deformation mechanism switch (Précigout and Gueydan, 2009). At higher water/rock ratio and temperatures below 700 °C, the role of serpentinites in active tectonic processes becomes crucial due to its unique rheological properties. Since the discovery of serpentinites at the Atlantic sea floor (Fig. 1) in the 60's (Aumento and Loubat, 1971; Hess, 1962), there has been a growing interest in the Earth Science community for this common rock (Coleman, 1977; Guillot and Hattori, 2013; O'Hanley, 1996). The purpose of this article is to review the tectonic significance of serpentinites at lithospheric plate boundaries. We will first discuss the origin, the mineralogy and the physical properties of serpentine minerals and then highlight the role of serpentinites in the main active tectonic settings.

## 2. Serpentine and serpentinite

### 2.1. Mineralogy

We summarize below the main mineral characteristics of serpentinites and serpentine minerals. For a more thorough mineralogical description, the reader may refer to Evans et al. (2013). Serpentinites are solid rocks consisting mostly of serpentine-group minerals, magnetite and sometimes brucite. Secondary minerals are also common, including talc, calcite and magnesite. Serpentinites result from the hydration of ultramafic rocks (dunite, peridotite and pyroxenite) at low (100 °C) to intermediate (700 °C) temperature (Fig. 2). The overall process of serpentinization can be portrayed by a general reaction of the type:

olivine + enstatite + $H_2O$ = serpentine + magnetite (+$H_2$).

The structural formula of serpentine minerals is $Mg_3Si_2O_5(OH)_4$. The incorporation of a few percentage of Al is common and stabilizes the serpentine at higher temperature (Ulmer and Trommsdorff, 1995; Wunder and Schreyer, 1997; Bromiley and Pawley, 2003; Hilairet et al., 2006; Padrón-Navarta et al., 2013), while the enrichment in Fe and particularly $Fe^{3+}$ takes place at low temperature in hydrothermal environments (Andreani et al., 2013). The peculiar rheological and geophysical properties of serpentinite are due to the specific crystallography of serpentine minerals. The structural unit of serpentinite is a polar 0.72 nm thick layer in which the Mg-rich trioctahedral sheet (O) is tightly linked to a single tetrahedral silicate sheet (T) on one side. On the other side, T–O layers are attached to the next T–O layers by weak H-bonding. To counterbalance the dimensional misfit between the larger T and O sheets, the layers are locally either curved or flat, which results in different types of serpentine.

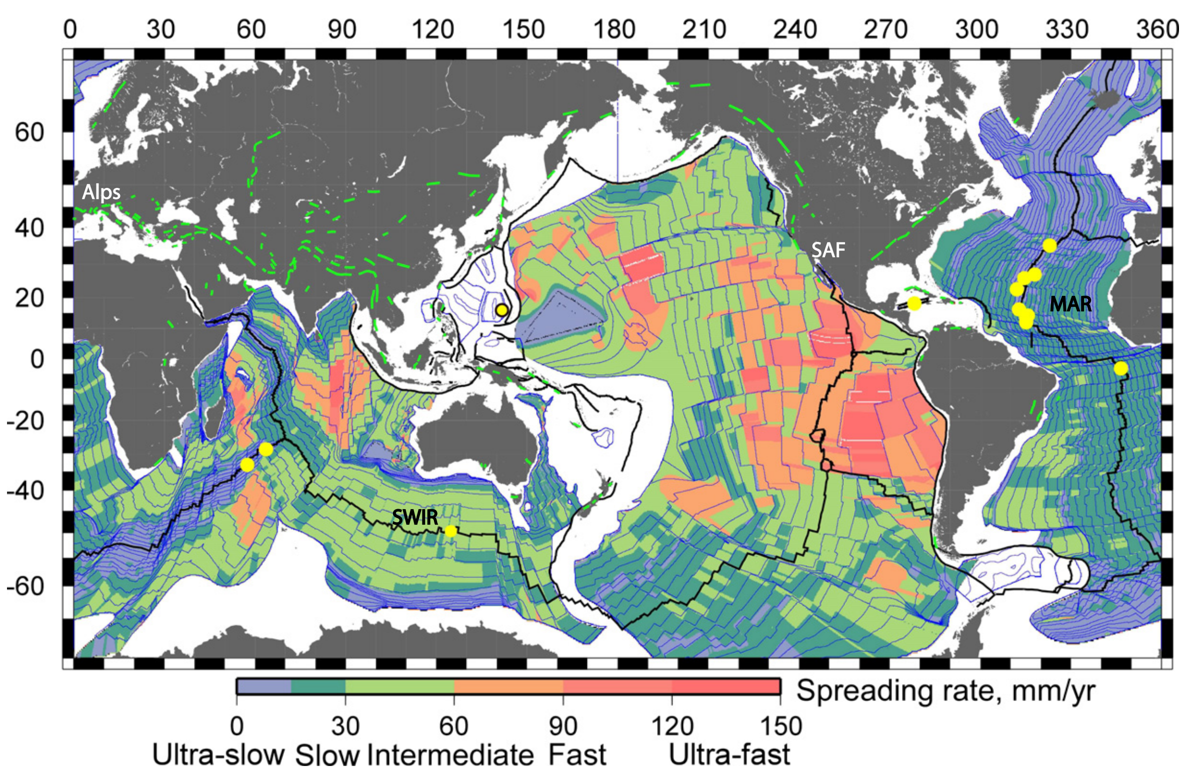


**Fig. 1.** Map of serpentinite occurrences on the seafloor and continents (modified after Guillot and Hattori, 2013). The oceanic lithosphere is colour coded for spreading rate (Cannat et al., 2010), and the black lines show the ridge axes. The major occurrences of serpentinite are shown by yellow circles for seafloor sites (courtesy of Javier Escartin) and by green lines on continents (based on Coleman, 1971). Serpentinites are also present on the ocean floor in the forearc regions of intra-oceanic, western Pacific arcs (Fryer et al., 1999).