

Simulation of low-temperature peridotites weathering in Mid-Oceanic Ridges

A.A. Novoselov

Vernadsky Institute

Most abyssal peridotites have the traces of the low-temperature submarine weathering (halmyrolysis). The reduced magnesium content over the silica one is a special feature of ocean ultramafic rocks contacted with cold seawater. The magnesium loss as against the initial bulk composition reaches about 5 wt. % [Snow and Dick, 1995]. On the other hand the decrease of magnesium content in peridotites can be a result of steatitization (the replacement of serpentine and other silicate minerals by talc). This process occurs due to hydrothermal alteration of substratum rocks at temperature above 350°C [Klein and Bach, 2009]. But the enrichment by Sr⁸⁷ and O¹⁸ shows that the transformation of these rocks is realized under seawater influence at temperature below 150°C [Snow and Dick, 1995]. This investigation aimed to simulate the low-temperature weathering of serpentinized peridotites under seafloor conditions.

Thermodynamic calculations with accounting of mineral dissolution kinetics were implemented on a basis of complex GEOCHEQ (thermodynamic data base derived from SUPCRT92) [Mironenko et al., 2008]. The iterative “washing” of serpentinite by seawater under seafloor conditions* was simulated. Modeling system was CO₂ open and the carbon dioxide partial pressure was 4·10⁻⁴ bar. The composition of spinel lherzolite (sample DR 37-14) [Silant'ev et al., 2011] have been used as an initial modeling substratum composition exposed to submarine weathering. This sample consists of 70% serpentine, 15% orthopyroxene, 7% clinopyroxene, 5% spinel and 3% olivine.

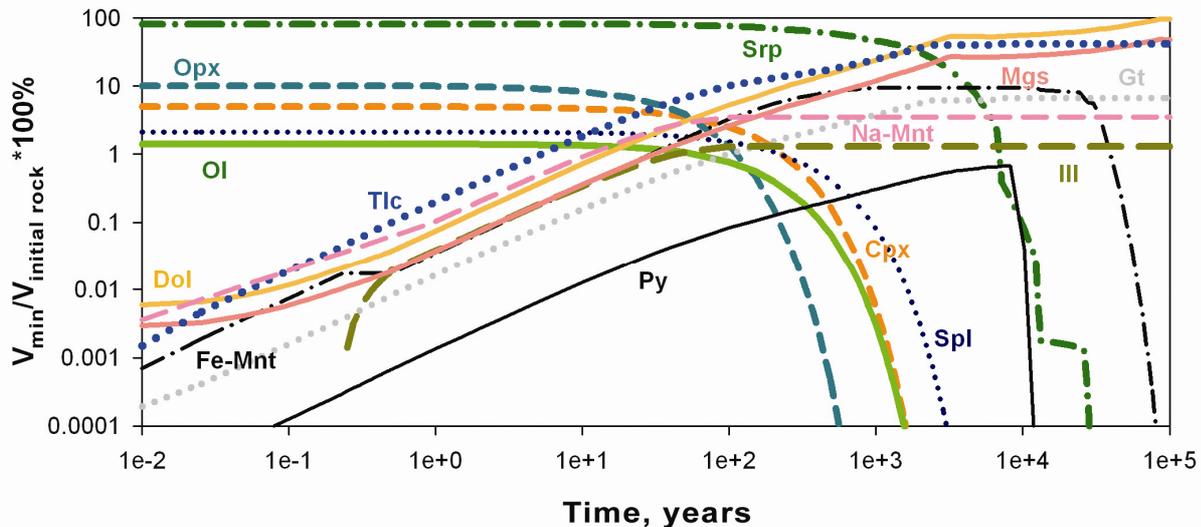


Fig. 1. The simulation of the mineral composition transformation of serpentinite as a result of weathering under seafloor conditions**

According received modeling results, the primary minerals were dissolved in the next sequence (Fig. 1): orthopyroxene (550 model years) → olivine (1550) → clinopyroxene (1600) → spinel (3000) → serpentine (29000). This row corresponds with literary data: clinopyroxene is the most maintained primary silicate phase [Snow and Dick, 1995], and spinel is the most stable primary mineral [Wang et al., 2009].

*The calculations were implemented at temperature 15°C and pressure 1 bar.

**Mineral symbols: Cpx - clinopyroxene, Dol - dolomite, Gt - goethite, Ill - illite, Mgs - magnesite, Na-Mnt – Na-montmorillonite, Fe-Mnt - nontronite (Fe-montmorillonite), Ol - olivine, Opx - orthopyroxene, Py - pyrite, Srp - serpentine, Spl – spinel, Tlc – talc.

The secondary talc which can be correlated with deweylite^{***} dominated at first stage of weathering until 3000 model years. Carbonates gradually started to prevail after serpentine dissolution. Before 25000 model years the weathering crust had a considerable value of nontronite, but after the complete serpentine dissolution it was effectively extracted from the rock. At final stage of forming the weathering crust consisted of carbonates (73 vol. %), talc (deweylite) (21 vol. %), goethite (3 vol. %), Na-montmorillonite (2 vol. %) and illite (1 vol. %). In the course of weathering the general volume of rock gradually increased to 2 times as against the initial volume (*Table 1*).

According literary data abyssal peridotites weathered at low-temperature contain the next mineral phases: aragonite, clay minerals including illite [Snow and Dick, 1995] and nontronite [Bach et al., 2001], talc [Wang et al., 2009], iron oxides and hydroxides that colour altered peridotites in reddish and bright orange [Luguet et al., 2003].

Table 1. The bulk composition transformation and the volume change of serpentinite as a result of submarine weathering. The results of numerical modeling

	Primary composition	250 model years	2250 model years	14 000 model years	100 000 model years
SiO ₂	46.58	46.04	39.07	29.66	22.62
Al ₂ O ₃	2.77	3.47	2.78	1.01	0.77
FeO	12.34	11.57	10.12	8.49	6.46
K ₂ O	0.10	0.09	0.06	0.07	0.05
CaO	1.14	3.57	11.22	18.46	23.41
MgO	36.55	35.09	36.69	42.23	46.62
Na ₂ O	0.52	0.17	0.07	0.08	0.06
V/V _{initial} *100%	100	111	151	140	198

At first stage (until 250 model years) the weathering crust bulk composition change characterized by magnesium loss (up to 1.5 wt. %) (*Table 1*) as a result of the primary silicate minerals dissolution and the replacement of them by talc (deweylite). Then the magnesium gain as carbonates began and the one content in the bulk composition significantly increased from the seawater source. Throughout the serpentinite washing by seawater, the relative value of silica, iron and alumina decreased. However it wasn't observed the loss or gain of these elements that is in accordance with Snow and Dick data [Snow and Dick, 1995]. It can be explained by the carbonates accumulation in the weathering crust and as a consequence the general volume increase. At ones the source of calcium can be both the weathered substratum and seawater [Brady and Gislason, 1997]. At the initial weathering stage the calcium content can archive 6.4 - 8.3 wt. % [Luguet et al., 2003].

To summarize, at first stage the weathering of serpentinitized peridotites under seafloor conditions characterizes by the magnesium loss as a result of the replacement of primary silicate minerals by talc (deweylite). Afterward the magnesium and calcium content significantly increases due to the carbonates accumulation in the weathering crust.

References

1. Bach W., Alt J.C., Niu Y., Humphris S.E., Erzinger J., and Dick H.J.B., The geochemical consequences of late-stage low-grade alteration of lower ocean crust at the SW Indian Ridge: Results from ODP Hole 735B (Leg 176) // *Geochimica et Cosmochimica Acta*, 2001, V. 65, No. 19, pp. 3267-3287.

***Deweylite is a clay-like alteration product defined as a compositionally variable mixture of poorly crystalline serpentine and talc or serpentine and stevensite. Generally, the deweylite assemblage is interpreted to form at low temperature due to alteration of ultramafic rocks [Beinlich et al., 2010].

2. Beinlich A., Austrheim H., Glodny J., Erambert M., Andersen T.B., CO₂ sequestration and extreme Mg depletion in serpentinized peridotite clasts from the Devonian Solund basin, SW-Norway // *Geochimica et Cosmochimica Acta*, 2010, V. 74, pp. 6935-6964.
3. Brady P.V., and Gislason S.R., Seafloor weathering controls on atmospheric CO₂ and global climate // *Geochimica et Cosmochimica Acta*, 1997, V. 61, No. 5, pp. 965-973.
4. Klein F., and Bach W., Fe-Ni-Co-O-S phase relations in peridotite-seawater interactions // *Journal of Petrology*, 2009, V. 50, pp. 37 – 59.
5. Lugué A., Lorand J.-P., and Seyler M., Sulfide petrology and highly siderophile element geochemistry of abyssal peridotites: A coupled study of samples from the Kane Fracture Zone (45°W 23°20N, MARK Area, Atlantic Ocean) // *Geochimica et Cosmochimica Acta*, 2003, V. 67, No. 8, pp. 1553-1570.
6. Mironenko M.V., Melikhova T.Yu., Zolotov M.Yu., Akinfiyev N.N., GEOCHEQ_M: Program complex for thermodynamic and kinetic modeling of geochemical processes in rock-water-gas systems. Version 2008 // *Vestn. Otdelenia nauk o Zemle RAN*, 2008, V. 26.
7. Silantyev S., Krasnova E., Portnyagin M., and Novoselov A., Silification of peridotites from the Stalemate Fracture Zone, NW Pacific: Tectonic and geochemical applications // *Workshop of German-Russian Project KALMAR, Trier, 16 - 20 May 2011. Abstract volume.*
8. Snow J. E., and Dick H. J. B., Pervasive magnesium loss by marine weathering of peridotite. // *Geochimica et Cosmochimica Acta*, 1995, V. 59, pp. 4219–4235.
9. Wang X., Zeng Zh., Liu Ch., Chen J., Yin X., Wang X., Chen D., Zhang G., Li K., Chen Sh., Ouyang H., Trace element composition of peridotites from the southern Mariana forearc: Insights into the geochemical effects of serpentinization and/or seafloor weathering // *Chinese Journal of Oceanology and Limnology*, 2009, V. 27, No. 4, pp. 985-992.