REE and stable isotope constraints on formation of metamorphic quartz veins: A case study from the Rhenish Massif (Germany)

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We have investigated fluid-rock reactions during formation of metamorphic quartz veins in the fold-and-thrust belt of the Rhenish Massif (Germany). The veins record two assemblages that were formed in an evolving fluid-rock system, which are (1) massive vein filling (elongate-blocky quartz, chlorite, apatite, albite) and (2) open space filling (euhedral quartz crystals, carbonates, sulfides). We performed a detailed REE and stable isotope study of vein minerals, altered wall rocks and precursor host rock metapelites. The REE and oxygen isotope data of vein quartz and altered wall rocks, combined with mass balance analysis, support that local mobilization of material was dominant during formation of the early massive vein assemblage, but that contributions from advecting fluids were also important. The strong shift in K/Na ratios in altered wall rocks and model fluid temperatures that are higher (350-400 °C) than estimates for the host rocks point to substantial fluid advection. Formation of the veins can be explained by a crack-flow-seal model, with multiple repetition of vein opening, fluid advection and vein sealing events. Each cycle was initiated with vein opening, resulting in enhanced permeability and considerable fluid advection and hydrothermal alteration of wall rocks. Conditions during each cycle evolved towards a decrease in fluid advection, coupled with substantial diffusional leaching of silica and precipitation in the veins. The formation of the later open space filling assemblage records transition from an advection- to a diffusion-dominated regime. This is supported by vein mineral and fluid inclusion textures recording conditions of undisturbed mineral growth, fluid inclusion data that point to a thermally equilibrated state (150-200 °C), and stable isotope data that demonstrate a local source for the vein minerals.

From anoxia to oxic conditions in the aftermath of oceanic anoxic event 2 (Late Cretaceous)

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Sections in the Ultrahelvetic units of the Eastern Alps (Austria) record oceanic anoxic event 2 (OAE 2) at the distal European continental margin of the western Tethys [1, 2]. Upper Cenomanian marl-limestone cycles are overlain by black, organic-rich (5% TOC, kerogen type II) layers, followed by Lower/Middle Turonian light grey to reddish marly limestones. Carbon isotope values display the well documented positive shift. The appearance of red-colored carbonates (CORB - Cretaceous Oceanic Red Beds) indicates a total time span of about 1.5 my for oxic bottom waters to become dominant. Orbital cycles of 400 kyr and 100 kyr frequencies are identified. Benthic foraminifera associations indicate repeated phases of enhanced organic matter flux and less aerated bottom waters during the transitional interval [3]. Sedimentation of red layers was controlled by periods of well oxygenated bottom waters, reduced sedimentation rates and degradation of organic matter in the underlying sediments. Principal component analysis of carbonate chemical data showed that the development of red coloured pelagic sediments is accompanied by a shift towards highly oligotrophic conditions in the surface ocean as well as a decrease in hydrothermal activity [4].

Higher up in the section, red limestone-marl cycles are present. Enhanced input of nutrient- like trace metals during episodes of higher volcanic activity is inferred, terrigeneous elements (Al, Li, Rb, Be) decrease upwards. Iron speciation data for marl and limestone layers attest to oxic early diagenesis during marl deposition compared to limestone episodes. Low sediment accumulation rates (2.5 mm/ka) are reconstructed. Geochemistry and stable isotope data indicate a highly oligotrophic environment with efficient recycling of organic matter and nutrients in the upper water column. Nutrient availability varied and resulted in periods of higher primary production. Iron oxides cause the red color in CORBs. The main fraction of iron in CORB sediments is fixed in silicate lattices and immobile.

[1] Neuhuber *et al.* (2007) *PPP* **251**, 222-238. [2] Wagreich *et al.* (2008) *Cret. Res.* **29**, 965-975. [3] Wendler *et al.* (2009) *SEPM Spec. Publ.* **91**, 209-221. Neuhuber & Wagreich (2011) *Sediment. Geol.* **235**, 72-78.