Mineralogy and Textures of Metal-rich Scales from the Reykjanes Seawater-dominated System, Iceland: Comparison with Seafloor Hydrothermal Systems

Vigdis Hardardóttir (vh@isor.is), Mark Hannington and Jeffrey Hedenquist

University of Ottawa, Department of Earth Sciences
140 Louis Pasteur, Ottawa ON
K1N 6N5 Canada

The Reykjanes high-temperature geothermal system is the onshore extension of the Mid-Atlantic Ridge in Iceland. The high-temperature liquid has salinity similar to seawater, but is depleted in SO_4^{-2} and Mg by two and three orders of magnitude, respectively, due to precipitation of anhydrite and magnesium minerals at depth. The liquid is enriched in SiO_2, K, and Ca relative to seawater due to reaction with the surrounding basalts. The range of inflow temperature to wells is between 275°C and 315°C. Hydrothermal manifestations at the surface cover 1 km^2, but the geothermal system is believed to be as large as 10 km^2 in the subsurface. It has been utilized discontinuously since 1983. Only two wells were in operation during this time and both were closed due to scaling, but 14 new wells have been drilled the last three years for power generation.

Scales that formed at the wellhead of one of the closed wells (no. 9, 35 bar-g well-head pressure) consist of fine black, sooty sulfides as well as bands 4 mm thick of very fine layers of anhedral sphalerite intergrown with chalcopyrite, galena, and clay minerals. In pipes on surface, upstream (on the high pressure side) of the orifice plate, the scales (<6 mm thick) are concentrated in layers at the bottom of the pipe, and consist of intergrown sphalerite ($Fe_{0.09}Zn_{0.87}Cu_{0.04}S$) and chalcopyrite ($Fe_{0.52}Cu_{0.48}S$), together with small grains of galena. Traces of pyrrhotite and smectite also have been identified by XRD. Wurtzite was identified at higher pressure in another well (no. 10) as well as anhydrite (no. 8). The dominant mineralogy of the scales changes progressively with decreasing pressure from wurtzite to sphalerite, chalcopyrite, pyrrhotite, galena, and amorphous silica. An amorphous iron silicate, similar to talc [composition $Fe_6Si_8O_{18}(OH)_6$] also becomes abundant with decreasing pressure.

On the downstream side of the orifice plate, where the pressure abruptly decreased by 20 bars, with a concomitant decrease in temperature, the scale forms a circular pattern of small ridges on the surface of the plate around the orifice. These consist of amorphous silica and sphalerite with traces of pyrrhotite and bornite. The volume of precipitates increases sharply downstream from the orifice plate, nearly completely clogging the pipe over a distance of 8 m, right after the orifice. Where the scales are thickest, only a 10 cm gap remains at the center of the 40 cm-diameter pipe (temperature ca. 215°C). The thickness of the scales diminishes at greater distances from the orifice, and they consist almost entirely of amorphous silica. In the first 100 m from the orifice plate, the amorphous silica is black, but 150 m from the orifice it becomes light gray, reflecting a gradual decrease in the abundance of sulfides or iron (?).

The form and texture of the scales also changes systematically downstream from the orifice plate and from the walls to the center of the pipe. Scales coating the downstream side of the orifice plate are hard and glassy, showing irregular clusters of domes close to the orifice which grade to ridges, then ripple-like ridges that appear to reflect fluid flow. These ridges vary from 2 mm to 1.5 cm in height. The scales lining the walls and the bottom of the pipe are distinctly layered (micron-scale layers), dense and black. In the interior of the pipe and further away from the orifice plate, the layers are thicker (up to 2 cm), lighter in color, and less dense. At distances of up to 8 m from the orifice plate, precipitates at the center of the pipe are unstratified and gravelly, possibly reflecting turbulent flow and mechanical reworking of the scales. Estimates of the scaling rates are 1.5 to 11 mm/year in well no. 9 but double that in well no. 10.

The bulk composition and mineralogy of the scales in the Reykjanes wells are strikingly similar to hydrothermal chimneys at submarine vents on the Mid-Atlantic Ridge, including recently discovered shallow submarine systems north of Iceland. The seafloor chimneys include a similar suite of sulfide minerals (wurtzite, sphalerite, chalcopyrite, pyrrhotite, bornite, and trace galena) as well as talc-like minerals and abundant amorphous silica that form at similar temperatures. Similar textures observed in the well scales are also recognized in the seafloor chimneys, including variations in the thickness and density of mineral layers that line the chimney walls, textural features characteristic of turbulent fluid flow, and features such as ribbing (small ridges) on the chimney walls. Although seafloor chimneys can grow rapidly in their early stages of development, radiometric dating indicates growth rates for mature structures that are similar to scaling rates observed in the Reykjanes wells. However, a major difference between mineralization in seafloor chimneys and in the Reykjanes wells is that a large proportion of the seafloor precipitation is due to mixing of high-temperature end-member fluids with cold seawater, causing precipitation of abundant anhydrite and Mg-silicates rather than Fe-silicates.