Biodurability of chrysotile and tremolite asbestos in simulated lung and gastric fluids

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ABSTRACT

Chrysotile [Mg₃Si₂O₅(OH)₄] and tremolite [Ca₂Mg₅Si₈O₂₂(OH)₂] asbestos represent two distinct mineralogical categories of regulated asbestos commonly evaluated in epidemiological, toxicological, and pathological studies. Human respiratory and gastric systems are sites of asbestos deposition where chrysotile and tremolite asbestos are undersaturated with respect to biological fluids and dissolution kinetics control the persistence of these minerals in biological environments. Here we examined the biodurabilities (i.e., the resistance to dissolution) of chrysotile and tremolite asbestos in simulated body fluids as a function of mineral surface area over time. Batch experiments in simulated gastric fluid (SGF; HCl and NaCl solution at pH 1.2) and simulated lung fluid (SLF; modified Gamble’s solution at pH 7.4) were performed at 37 °C over 720 h to evaluate the dissolution of chrysotile vs. tremolite asbestos in acidic and near-neutral biological fluids. The rate-limiting step of Si release for both minerals was used to obtain rate constants (k) and reaction orders (n) allowing comparisons of mineral dissolution rates. Both chrysotile and tremolite asbestos are less biodurable in SGF (low pH) compared to SLF (near-neutral pH). Based on equivalent surface area comparisons, the surface chemistry of tremolite is more reactive in lung fluid than chrysotile and vice versa in digestive fluid. However, the relative biodurabilities of these asbestos silicates (from most to least) are tremolite (SLF) > chrysotile (SLF) > tremolite (SGF) > chrysotile (SGF) when accounting for the greater surface area of chrysotile per mass or per fiber compared to tremolite. Overall, this study illustrates the importance of surface area and fiber morphology considerations when evaluating the biodurabilities of asbestiform minerals.

Keywords: Chrysotile, tremolite, serpentine, amphibole, asbestos, dissolution, biodurability

INTRODUCTION

Asbestos is a carcinogenic material associated with cancer of the lung (lung cancer and mesothelioma), asbestosis (fibrosis of the lungs), and gastrointestinal cancer (Rom and Palmer 1974; Maresca et al. 1984; Mossman and Churg 1998; Skinner et al. 1988; Holland and Smith 2001; Yano et al. 2001; Roggli et al. 2002; Bernstein et al. 2005, 2006; Pfau et al. 2005; Committee on Asbestos 2006; Plumlee et al. 2006; Gunter et al. 2007; Yarborough 2007). These diseases have been primarily ascribed to the inhalation and ingestion of airborne asbestos particles. Identifying the relationship between asbestos and human toxicity is problematic due to asbestiform minerals having an array of compositions, atomic structural arrangements, and fiber morphologies (i.e., fiber size, length, diameter, and shape) that affect biogeochemical reactions in the body. The multiplicity of potential solution-mineral interactions provides an opportunity to further explore and comparatively evaluate the biodurabilities (i.e., the extent kinetics controls mineral dissolution in body fluids where greater resistance to dissolution makes a material more durable) inherent between two common regulated categories of asbestos: chrysotile (serpentine asbestos; phyllosilicate) and tremolite (amphibole; joinosilicate) asbestos. One major factor complicating comparative biogeochemical breakdowns between chrysotile and tremolite asbestos is the greater surface area (per mass or per fiber) of chrysotile compared to tremolite. This surface area discrepancy is a result of chrysotile’s “curled sheet” structure compared to tremolite’s “needle-like” structure.

The purpose of this study is to develop and compare dissolution rates for chrysotile and tremolite asbestos in biological fluids utilizing mineral surface area considerations that directly reflect bulk mineral-solution interactions. Here we investigated biodurabilities by monitoring Si release from both chrysotile and tremolite asbestos in simulated body fluids as a function of surface area over time. Batch dissolution experiments were performed at body temperature (37 °C) to examine asbestos biodurabilities in a slightly salty, acidic digestive fluid [simulated gastric fluid (SGF)] juxtaposed to the higher ionic strength, near-neutral pH lung fluid [simulated lung fluid (SLF)]. Although these experiments do not replicate the complexity of the human body and the multitude of processes that may occur, they do provide a benchmark to evaluate the biological breakdown of two mineralogical forms of asbestos at both acidic and near-neutral pHs.