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SPECIALTY GRAND CHALLENGE
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Grand Challenge for Frontiers in Environmental Chemistry—Inorganic Pollutants

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Documentation of the impacts of human activities and climate change on the biosphere has exploded in the last decade with an exponential increase in publications that have described the increasing environmental insult from inorganic and organic compounds, and their effects on humans, wildlife and other organisms (Stumm and Morgan, 1996; Mason, 2013; Williams and Crutzen, 2013; Ali and Khan, 2017; Fairbrother et al., 2019). However, there has been less study of the underlying environmental (biogeochemical) processes that govern the extent of the impact, and its regional variation, and most studies have not examined the underlying chemical processes and reactions that enhance or mitigate the impact of pollution generally, or that of a particular contaminant (Jiang et al., 2012; Lichtfouse et al., 2014; Brooks et al., 2016; Ali and Khan, 2017). Additionally, most studies have focused on a specific reservoir of the biosphere (the atmosphere, terrestrial landscapes, freshwaters, and the ocean) with few studies examining the linkages between these reservoirs and the processes controlling the exchange of chemicals across these interfaces. Additionally, anthropogenic sources deliver chemicals to the geochemical reservoirs in different forms, and their long range transport and dispersion depends on the reservoir, with chemicals typically traveling further if emitted to the atmosphere, and least if deposited into terrestrial landscapes. Chemical transformations during transit, or after deposition to soils/sediments, can radically change the long-term fate of a released contaminant (Jardim, 1998; Cai and Braids, 2003; Fedotov, 2014; Ali et al., 2019; Burri et al., 2019), and its eventual impact on the receptors of concern. While environmental impact and contaminant bioaccumulation and deleterious effects are clearly modified by chemical processes occurring in water, sediments, soils and the atmosphere, these processes are rarely studied in concert with the determination of contaminant body burdens (Ali et al., 2019; Fedotov et al., 2019; Adams et al., 2020). For example, a Scopus search with the keywords "mercury" and "environmental chemistry" yielded 62 results while a search for "mercury" and "biota" yielded 1,061. Few of the studies examining tissue contaminant burdens probe the underlying processes (Morel and Hering, 1993; Hunter and Beveridge, 2010; Lavoie et al., 2016; Ali et al., 2019), instead focusing mostly on relating burdens to the magnitude of the primary environmental anthropogenic inputs, without considering the intermediate processes and transformations.

Many of the most important global environmental disasters or sources of largescale contamination have been due to inorganic pollution (Ali and Khan, 2017 and references therein); e.g.: (1) the extensive contamination of the waters around Minamata, Japan with mercury (Hg) and methylmercury (MeHg) and the resultant human impacts (Matsuyama et al., 2011; Akito et al., 2014); (2) the "acid rain" impacts from emissions of sulfur and nitrogen oxides from energy generation on the environment (Seinfeld and Pandis, 1998); (3) eutrophication of waters by nutrients and their effects on oxygen levels and fish and aquatic habitat (Roulet and Moore, 2006; Brooks et al., 2016); (4) the impacts of emissions from alkyl lead (Pb) additives in gasoline

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on humans (Mason, 2015; Frank et al., 2019; Roy and Edwards, 2019); (5) impacts of inorganic compounds used in anti-fouling paints (e.g., tributyl tin) and wood treatment (e.g., arsenic (As) and copper (Cu); (Van Wezel and Van Vlaardingen, 2004); (6) the extensive impacts on the environment and humans from releases of metals and other contaminants from mining activities (e.g., As, Hg, Pb, Hg) and coal burning (e.g., Hg, cadmium (Cd), selenium (Se); Zhao et al., 2017; Rezaie and Anderson, 2020); (7) the use of Hg, Pb, and cyanide in precious metal [gold (Au) and silver (Ag)] extraction (Mason, 2015; Cooke et al., 2020; Moreno-Brush et al., 2020); and (8) most recently, the impacts from the release of manufactured nanoparticles (e.g., Ag, CdSe) into the environment (Handy et al., 2008; Nick et al., 2014) and the increase in e-waste contamination (Robinson, 2009). Many of these examples highlight another aspect of focus for environmental chemists—the study of chemicals in their source environments and their transformations during processing (e.g., during metal processing, energy generation, and other industrial processes, and in sewage treatment facilities) as well as in the receiving environments of the waste streams, which often are where the environmental hazards are manifesting through human and environmental impacts. Finally, there is a large legacy of pollution in the environment from historical releases of pollution and their long-term fate and effects needs to be examined (Mason, 2013, 2015; Cooke et al., 2020).

For pollutants, the form and chemistry in the environment—dissolved, colloidal or particulate—and for inorganic chemicals, their chemical nature (speciation/oxidation state/particle reactivity) are strong determinants of their impact with, and accumulation into organisms (Morel and Hering, 1993; Mason, 2013; Adams et al., 2020), and their fate and transport through the environmental reservoirs. Detailed knowledge of the chemistry and environmental transformations of inorganic pollutants, primarily metals, metalloids and nutrients, is fundamental to our understanding of the anthropogenic and climate influences on their fate in the environment and impact on humans and other receptors. Furthermore, there is a need to measure more than the total concentrations as the chemical forms need to be assessed as each have a different impact, and chemical complexation and other interactions can modify toxicity (Morel and Hering, 1993; Eggen and Suter, 2007; Lavoie et al., 2016; Adams et al., 2020). Using Hg as an example, there are now many papers demonstrating that there is little correlation between total Hg concentrations in sediments and water and those of the residing biota (primarily MeHg in higher trophic level organisms), because there are complex biogeochemical factors that control the net conversion of inorganic Hg to MeHg, the most toxic and bioaccumulative form, and further that water chemistry substantially alters the rate of MeHg accumulation at the base of the food chain (Driscoll et al., 2012, 2013; Chen et al., 2014; Hsu-Kim et al., 2018; Schartup et al., 2019). The same is true for other metal(loid)s and inorganic pollutants (Mason, 2013). Knowing the total concentration of an element in the environment is insufficient to understand its environmental fate and impact.

Even though many redox and organometallic transformations in the environment are microbiologically-mediated, chemistry plays a fundamental role in modifying the bioavailability of elements to the microorganisms, for both dissolved species and those associated with sediments and soils (Hunter and Beveridge, 2010; Fedotov, 2014; Adams et al., 2020). For many inorganic pollutants, there are multitude *in situ* transformations that alter their fate, transport and bioaccumulation, as their various oxidation states behave very differently (e.g., differences in the solubility of Pb(II) and Pb(IV) contributing to drinking water contamination; Roy and Edwards, 2019). Photochemical transformations are important in the atmosphere and in surface waters (Seinfeld and Pandis, 1998; Colbeck, 2009). Also, many metal(loid)s can be transformed into organometallic compounds, which can be more or less toxic than the inorganic element (e.g., MeHg is more toxic than inorganic Hg but methylated As and other As-containing organic compounds are less toxic than inorganic As; Cai and Braids, 2003; Craig, 2003; Mason, 2013). Additionally, the exponential rise in the manufacture of inorganic nanomaterials, which are being released into the environment, and the growing realization that there are inorganic nanomaterials/colloids naturally formed in the environment that behave very differently than larger particulate, provides further justification for an urgent need to understand their environmental chemistry and fate (Handy et al., 2008; Suib, 2013; Nick et al., 2014).

There are currently about 20 journals that publish papers with an environmental chemistry focus, but most of these journals cover a wider range of topics, including bioaccumulation, microbial transformations, toxicology, human impacts and risk assessment, and deal with both inorganic and organic chemicals (Ali and Khan, 2017). The journals primarily focused on environmental chemistry are specific to one reservoir, and mostly are focused on atmospheric chemistry, and focus on both inorganic and organics contaminants. The journals range widely in their Impact Factor (Ali and Khan, 2017). Clearly, there is a strong need for a journal focused on environmental chemistry and encompassing all reservoirs and media, and the challenge is to provide a suitable vehicle to achieve this goal. Given the environmental complexities of inorganic pollutants and the importance of understanding their environmental chemistry throughout the biosphere, there is evidently a need for a journal that is not limited in its focus to one reservoir, and which has a strong emphasis on basic environmental chemical principles and focuses on understanding the chemical mitigation or enhancement of the impact of global pollution and climate change at local, regional and global scales.

The *Grand Challenge* of the journal *Frontiers in Environmental Chemistry—Inorganic Pollution* is therefore to promote understanding of the chemical factors and processes that translate and modify the anthropogenic and climate impacts of releases of inorganic chemicals into the biosphere, so that society can adequately and accurately devise approaches and methods to mitigate these impacts through global regulation of emissions and ecosystem management. Understanding of the chemical reactions that occur is fundamental to pollution reduction and mitigation and to the construction of biogeochemical and ecosystem models needed to predict future environmental change, and understand what has happened in the past.

Current modeling efforts are not only limited by the lack of environmental measurements for many of the most important environmental pollutants, but also by the lack of the details of the kinetic and thermodynamic parameters of the governing environmental transformations. Understanding these processes requires fundamental studies with novel approaches and detailed chemical characterization, and modeling of these studies, and the journal will be focused on publishing such endeavors.

Overall, the focus will be on the environmental chemistry of inorganic pollutants, such as metals, metalloids and nutrients, and their reactions within the environment, and the examination of the mechanisms driving these transformations. One challenge is to understand the chemistry of the transformation of inorganic elements into their naturally-derived low molecular weight alkyl derivatives (e.g., MeHg, methylated arsenic compounds) and also the transport and degradation of manufactured alkylated compounds (e.g., tetraethyl lead, tributyltin), as such transformations can make these elements more or less toxic (Craig, 2003; Mason, 2013). A strong focus on atmospheric chemical reactions, aerosol chemistry, gas-particle interactions, and the chemistry of air-water exchange of inorganic pollutants (Seinfeld and Pandis, 1998; Colbeck, 2009) needs to be coupled with studies in fresh and marine surface waters, groundwater, and the terrestrial environment, and at the water-solid interface (Mason, 2013; Zhao et al., 2017; Burri et al., 2019). Abiotic chemical and photochemical transformations of elements and inorganic compounds are an important part of their chemical cycles, with studies not limited to the atmosphere and water, but also the reactions and processes occurring in soils and sediments. Redox chemistry has an important role in many of these transformations. Furthermore, understanding of the diverse impacts of natural and manufactured inorganic nanoparticles and colloids in the environment has increased tremendously but there is a need to further study of their environmental fate, transport and transformations (Handy et al., 2008; Nick et al., 2014). In terms of study, the journal will focus on both laboratory and field studies, and also include examination of environmental chemical processes using stable and radioisotopes measurements to inform understanding of inorganic pollutant chemistry (Li et al., 2019). Modeling studies which include environmental chemistry are also needed to allow for integration and projection of current and future trends (Kroeze et al., 2016; Matthias et al., 2018; Ménesguen and Lacroix, 2018).

Environmental impacts come from direct inputs of pollutants to the environment from point and non-point sources as well as remote impacts due to the environmental long-range transport of pollutants through the biosphere (primarily, aquatic ecosystems, and the atmosphere), that ignore international and continental boundaries. There is the lack of synthesis of these studies and an increasing need for cutting edge research that is focused on environmental chemical interactions and processes across the aquatic, terrestrial, and atmospheric realms of the biosphere. Studies examining chemicals and complexes of all elements in the periodic table, except those that have a carbon backbone, would be acceptable to the focus of the journal. The section will focus on understanding the transport of inorganic pollutants, their environmental transformations into more toxic or benign forms, and the chemistry influencing their interaction with biological tissue. The interaction of these chemicals with natural organic matter in the environment is also an area of focus as this can dramatically alter the dissolved-particulate chemical interactions of inorganic pollutants, and their bioaccumulation (Stumm and Morgan, 1996; Mason, 2013).

In conclusion, further publication of articles focused on cutting edge and relevant environmental chemistry is crucial as there is the expectation that a clearer understanding of these chemical processes, and the enhanced quantification of rates and extent of environmental chemical transformations, will aid in mitigation and assessment of environmental risk to receptors, and will allow for sound management of the impacts of anthropogenic releases and climate change. The need to provide sound chemical science to support risk assessment and mitigation of pollution, and the concurrent impacts of climate change, is a fundamental challenge for environmental chemists.

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The author confirms being the sole contributor of this work and has approved it for publication.

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