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Trace metals, radionuclides, and strontium isotopes variations of global phosphate rocks and fertilizers: Implications for tracing environmental impacts

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Phosphorus is one of the primary nutrients essential for plant growth and thus its availability is critical for sustainable agricultural development and food security. Increased utilization of P-phosphate fertilizer over the last decades has caused eutrophication of numerous water resources. Elevated levels of metals and metalloids in phosphate rocks and P-fertilizers pose less recognized but significant potential risks to soil and water quality. Here we present trace element concentrations and Sr isotopes data in sedimentary and igneous phosphate rocks from worldwide major phosphate producing countries. The data show that young (<100 Ma) sedimentary phosphate ores from the Eastern U.S. and the Tethys Belt of Northern Africa and Middle East exhibit high concentrations of uranium, cadmium, arsenic, and chromium, while older phosphate ores from China and India show significantly lower levels of these metals. Systematic analysis of several pairs of phosphate ores and P-fertilizers indicates selective enrichment of trace elements in P-fertilizer, including uranium, cadmium, and chromium, resulting in elevated levels of these toxic elements in major P-fertilizers such as those utilized in the U.S. In contrast, phosphogypsum, which is the major byproduct and the solid waste of P-fertilizer production, is characterized by enrichment of ^{226}Ra over uranium. The extensive use of P-fertilizers infers continuous input and accumulation of toxic metals on in agriculture soils. Over long-term, metalloids like uranium, arsenic, and chromium would likely to be mobilized with water infiltration to deep soils and/or underlying groundwater, whereas cationic metals like cadmium would accumulate in surface soils. To detect the impact of P-fertilizers in the environment, we propose using Sr isotopes as a diagnostic tracer for detecting the impact of phosphate mining and fertilizers applications in the environment. We show negligible Sr isotope fractionation during production of P-fertilizers, which provides a novel methodology to detect the mobilization of P-fertilizers-derived metal(loid)s in agricultural soils and impacted water resources.