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Geochemical Fingerprinting of Cements and Constituent Raw Materials for Provenance Determination

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U.S. cement imports have risen steadily in recent years, with more than one quarter of domestic consumption now sourced from abroad. At the same time, in the U.S context the supply chain for imported cement can lack transparency due to the involvement of third-party importers and numerous upstream suppliers of raw materials. This opacity makes it difficult to verify the environmental and labor conditions under which raw materials are extracted. Drawing on isotopic methods commonly used in archaeological provenance studies, we explore the use of $^{87}Sr/^{86}Sr$, $\delta^{34}S$, and elemental profiles to trace cement constituent material provenance and improve supply chain transparency.We measured $^{87}Sr/^{86}Sr$, $\delta^{34}S$, and elemental concentrations in cement and paired limestones and gypsums from 17 domestic plants (N = 51 samples) as a proof of concept. Our results expand upon prior work leveraging $^{87}Sr/^{86}Sr$ for geochemical fingerprinting of cement [1][2] by directly measuring $^{87}Sr/^{86}Sr$ in both cement and paired source limestones, demonstrating that cement values are consistently elevated relative to the limestones, which more closely preserve primary seawater $^{87}Sr/^{86}Sr$ signatures associated with depositional age. This misalignment confirms that additional Sr is introduced into cement from non-limestone raw materials, thereby increasing the $^{87}Sr/^{86}Sr$ ratio and complicating efforts to provenance cement by directly linking it to limestone formations of different ages. We also introduce $\delta^{34}S$ as a new measure for fingerprinting cement, and demonstrate that $\delta^{34}S$ is capable of indicating if natural or synthetic gypsum was used in cement production. Given that cement is a complex manufactured material that undergoes substantial processing and incorporates multiple raw inputs, much like archaeological artifacts, additional isotope systems should be explored to link cement to other key raw materials, including shale, bauxite, sand, and iron ore. Integrating multiple isotopic tracers can strengthen modern supply chain transparency while also informing reconstructions of past trade routes and production processes in archaeological contexts.

[1] Kazlagić, Stephan, Ostermann, Possolo & Vogl (2024), *Advances in Cement Research* **36**(6), 260–271.

[2] Graham, Goguel & St John (2000), *Cement and Concrete Research* **30**(7), 1105–1111.