SmartNotes

How do isotope fingerprints support forensic investigations?

Introduction

Forensic investigations examine sample materials to determine how similar or different they are, or to identify the origin of the material. Identifying the difference in a material or where it comes from can be achieved because materials have a unique chemical signature, like a fingerprint. To visualize this fingerprint, Isotope Ratio Mass Spectrometry (IRMS) is used, measuring the stable isotopes of sample material that are essentially chemically identical. Unlike other types of inferential evidence in forensic investigations (e.g., bite marks, impression marks from tires or footwear, handwriting), isotope measurements are quantitative empirical evidence that are reproducible and easy to validate. The application of isotope fingerprints to forensic investigations has become more commonplace because there is a need for a rigorous scientific foundation underpinned by sound analytical techniques. Application areas include forensic investigations on human, criminal, environmental, ecological, food and archaeological materials.

Isotope fingerprints in forensics

Isotope fingerprints in forensic materials are related to natural processes and geographical regions and can define differences in sample materials. This means that forensic sample materials can be put into a geographical context, so that their origin can be traced, or understood with respect to a specific process or set of processes in nature, such as botanical (timber, food, skeletal remains), dietary and food web variations (skeletal and animal remains, human and animal tissue) and geographical location (skeletal remains, narcotics, explosives, packaging, gemstones). Table 1 provides a non-exhaustive summary of isotope fingerprints in forensic applications. These natural process can be traced using carbon, nitrogen, sulfur, oxygen and hydrogen isotope fingerprints encoded in the sample materials. However, in the case of explosives, these isotope fingerprints trace factory production efficiency and processes.

Table 1.

Isotope Fingerprint	What is the biogeochemical interpretation?	Example forensic interpretation	What sample types can be analyzed?
Carbon	Botanical processes (C3, C4 and CAM Photosynthesis), plant rate of uptake of carbon (differentiate region plant is from, such as tropical vs. temperate), source rock geology, factory production processes/batch processes	Human (dietary preferences, travel history, and provenance), food (labelling authenticity) tracing packaging, arson	Bones, teeth, hair, nails, food, timber origin, oil, narcotics, cellotape, matchsticks
Nitrogen	Nitrogen fixation (trophic level differentiation: herbivore vs. carnivore vs. omnivore), factory production processes	Human (dietary preferences, travel history, and provenance), food (labelling, authenticity)	Bones, teeth, hair, nails, food, explosives, oil, narcotics
Sulfur	Incorporated into plant and animal tissue from bedrock uptake/weathering, atmospheric deposition (sea spray, geological origins, pollution) and microbial activity	Human (dietary preferences and provenance), food (origin)	Bones, teeth, hair, nails, food, timber origin, human and animal tissue, oil
Hydrogen	Principally related to local-regional rainfall, or water transport regimes, and hence geographical area, factory production processes/batch processes	Human (travel history and provenance), synthetic and narcotics (geographical origin), food and beverage (authenticity and origin), tracing packaging, arson	Bones, teeth, hair, nails, animal horn, narcotics, food and beverage, timber origin, oil, matchsticks
Oxygen	Mainly related to local-regional rainfall, or water transport regimes, and hence geographical area, factory production efficiency	Human (travel history and provenance), synthetic and narcotics (geographical origin), food and beverage (authenticity and origin), tracing packaging, arson	Bones, teeth, hair, nails, animal horn, narcotics, food and beverage, timber origin, explosives, matchsticks

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The application of isotope fingerprints in forensics brings unique capabilities to the laboratory and to the forensics field that increasingly demands a quantitative empirical evidence base that is reproducible and easy to validate. Applying isotope fingerprints to forensic questions allows investigators to provide a unique characterization of the sample material and so trace reactants, chemical pathways and reaction conditions, relative to natural processes, and then compare materials of interest to others collected, or to an authentic reference material[1]. In addition, investigators may also implement predictive models for environmental parameters, such as rainfall, geological bedrock, temperature, land use, for example[1].

From this basis, using isotope fingerprints makes it possible to determine similarities between different drug seizures and authentic material and to follow trafficking routes to their original source[2]. The same principle can be applied to other criminal materials such as explosives[1], artefacts and gemstones, human remains, human and animal migration and movements, oil spills, food and beverage origin and authenticity, synthetic drugs, arson investigations and plant and wood product origin, and be used to answer questions on material origin and authenticity[1].

Analytical solution for detecting isotope fingerprints

IRMS works by measuring the "isotope fingerprint" of a sample, a unique chemical signature that changes from sample to sample. There are a number of approaches to preparing sample materials for isotope analysis. However, the fundamental process for IRMS is the conversion of a solid or liquid sample to a gas under high temperature. In the case of EA-IRMS and GC-IRMS the conversion of the sample to a gas is performed by two processes: combustion and pyrolysis. Combustion, burning the sample at around 1000 ˚C with oxygen, is used to evolve carbon, nitrogen and sulfur from the sample in the form of N^2, CO_2 and SO_2. Pyrolysis, breaking down the sample at 1400 ˚C in a reductive environment, is used to evolve hydrogen and oxygen from the sample, in the form of H^2 and CO. After the gases are produced, they are separated from one another using gas chromatography and then transferred in a continuous gas flow to a detector that measures the isotope fingerprint of the sample. In addition, gas samples can be directly analyzed.

The dedicated solutions of the Thermo Fisher Scientific™ stable isotope portfolio are designed to offer different capabilities and performances, with dedicated features for the coupling to the Thermo Scientific™ IRMS Systems, according to the varying analytical needs of laboratories working for routine and research applications:

- the Thermo Scientific™ EA IsoLink™ IRMS System, for analysis of bulk sample material;
- the Thermo Scientific™ GC IsoLink II™ IRMS System, for analyzing specific compounds from a bulk sample material;
- the Thermo Scientific™ LC IsoLink™ IRMS System, for analyzing specific compounds from a bulk sample material in liquid form;
- the Thermo Scientific™ GasBench II System, for the analysis of gas samples evolved from bulk sample materials.

References

1. Chesson, L.A., Tipple, B.J., Howa, J.D., Bowen, G.J., Barnette, J.E., Cerling, T.E., Ehleringer, J.R. Treatise on geochemistry (2nd Ed.), Vol. 14, 285-317.
2. Mallette, J. R., Casale, J.F., Jordan, J., Morello, D.R., Beyer, P.M. Nature Sci. Rep. 23520-23530.

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