Copper isotopes

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Definition

Copper (Cu) has two isotopes: ^{63}Cu and ^{65}Cu. Both are stable, with natural abundances of 69.174% and 30.826%, respectively (Albarède 2004). The distribution of these Cu isotopes in nature is defined by the equation: $\delta^{65}\text{Cu} = [(^{65}\text{Cu}/^{63}\text{Cu})_{\text{sample}}/(^{65}\text{Cu}/^{63}\text{Cu})_{\text{standard}} - 1] \times 1000$.

Overview

Cu is a transition metal that rarely occurs in its native form (Cu^0) (Dekov et al. 2013). It is, however, abundant in oxygen-poor environments as Cu^+ and Cu^{2+} when conditions are partially to fully oxygenated (Chi Fru et al. 2011; Dekov et al. 2013; Moynier et al. 2017). The oxygen-driven transformation of Cu results in isotopic fractionation between precipitated minerals and the solutions from which they formed (Zhu et al. 2002; Ehrlich et al. 2004; Dekov et al. 2013; Moynier et al. 2017). Cu readily binds to sulfide, leading to Cu being hosted by sulfide minerals in differentiated magmas and volcanic rocks, but rarely in the silicate mineral phases that make up a bulk of volcanic rocks (Albarède 2004).

The Cu minerals in volcanic rocks weather as a function of oxygen availability to form soils and sediment minerals. This quantifiable relationship between rock Cu minerals and oxygen-driven weathering has been used to link Cu to the permanent rise of oxygen in Earth's atmosphere during the so called Great Oxidation Event (GOE) that occurred ~2.45 billion years ago (Chi Fru et al. 2016). At this time, atmospheric oxygen rose from below 10^{-5} present day levels and climbed to at least 10% of the modern value (Lyons et al. 2014). It is thought that the replacement of terrestrial detrital iron sulfide-rich beds by iron (oxyhydr)oxide-rich layers after this time was a result of the progressive oxidation of the sulfide minerals as appreciable amounts of oxygen became a permanent fixture of the atmosphere (Holland 2006). The evidence shows that the oxygen weathered and transformed a major sulfide reservoir that had accumulated on the continents in the absence of oxygen in the atmosphere before 2.45 billion years ago (Canfield 1998; Konhauser et al. 2011).

As a corollary, the weathering of Cu sulfides on land discharges fluids enriched in heavy ^{65}Cu (Moynier et al. 2017). This is consistent with the enrichment of ^{65}Cu in modern, sulfate-rich seawater and sediments (Dekov et al. 2013; Takano et al. 2014; Moynier et al. 2017). In addition, the binding of Cu by iron (oxyhydr)oxide minerals precipitating from the water column removes heavy ^{65}Cu from solution (Pokrovsky et al. 2008; Ballistrieri et al.

2008). It is, therefore, believed that a change in the isotopic signature of Cu in marine, organic carbon-rich sediments following the GOE was impacted by the weathering of continental sulfide minerals and the difference in the volume of banded iron formation (BIF) that was precipitated before and after the GOE (Fig. 1).

Living cells incorporate light ^{63}Cu into biomass (Zhu et al. 2002; Navarette et al. 2011). This has particular implications for biological complexes and enzymes that catalyse important biogeochemical processes, including aerobic methane-, iron- and ammonia-oxidation, the reduction of nitrate to nitrogen gas, and in some aspects of photosynthesis (Zahn et al. 1996; Zumft 1997; Chi Fru et al. 2011, 2011; Ilbert and Bonnefoy 2013).

Taken together, the conceptual model presented in Figure 1 suggests that the redox sensitivity of Cu makes it a robust biogeochemical tool for remotely identifying worlds with atmospheric compositions of the past, present and future that can sustain Earth-like life forms. This important criterion arises from the ability of Cu isotopes preserved over long geological timescale in rocks that interacted with the atmosphere and biosphere to differentiate the oxygenation state in which they formed. Because oxygenation is primarily a strong property of the Oxyphotobacteria that invented oxygen-producing photosynthesis, it is an expressed signature for Earth-like life conditions.

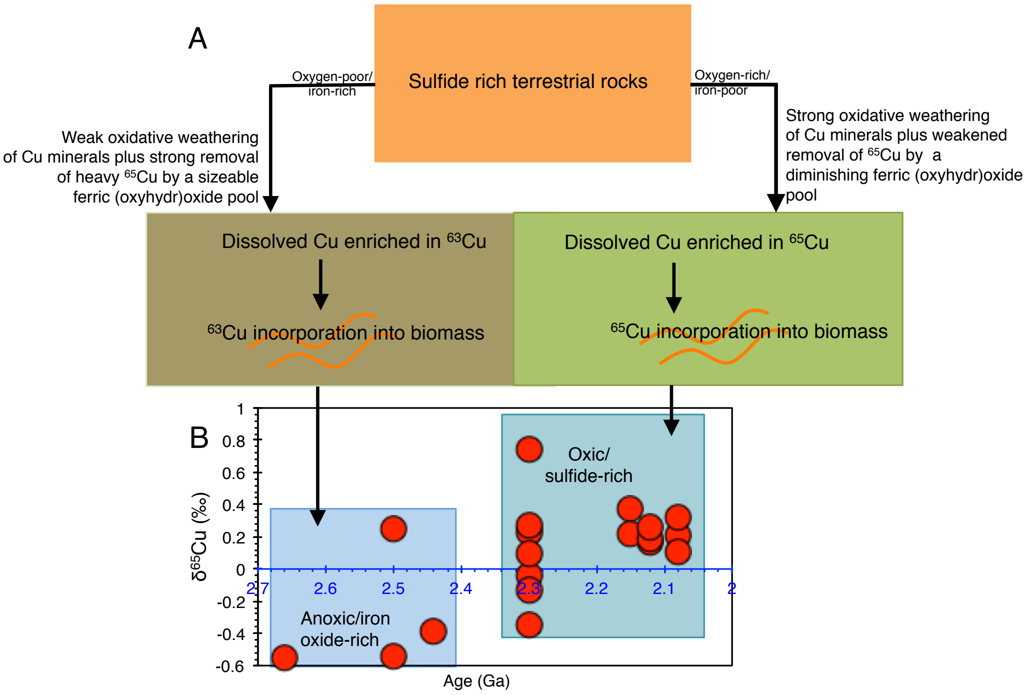

Fig. 1. (A) Conceptual model for the fractionation of Cu isotopes in anoxic and oxic atmospheres linked to the weathering of continental sulfide minerals, adsorption by iron (oxyhydr)oxides and biological incorporation into biomass. (B) Cu isotope fractionation and preservation in organic carbon-rich sediments deposited under oxygen-poor and oxygen-rich atmospheres before and after 2.5 billion years ago (Chi Fru et al. 2016).

Cross-References

Aerobic photosynthesis
Ammonia
Archean Environmental Conditions
Archean Eon
Archean Traces of Life
Astrobiology
Bacteria
Banded Iron Formation
Biogenicity
Biogeochemical Cycles
Biomarkers
Biomarkers Atmospheric, Evolution Over Geological Times
Biomineralization
Bioprecipitation
Biosphere
Chemolithoautotroph
Chemolithotroph
Colonization, Biological
Continental Crust
Continents
Cyanobacteria
Denitrification
Earth, Surface Evolution
Earth’s Atmosphere, History of the Origins
Earth’s Atmosphere, Origin and Evolution of
Environment
Evolution, Chemical
Fractionation
Fractionation, Mass Independent and Dependent
Geomicrobiology
Great Oxidation Event
Iron Cycle
Iron Oxides, Hydroxides and Oxy-hydroxides
Isotope Biosignatures
Isotope Ratio
Ocean, Chemical Evolution of
Oxic
Oxic Sediments
Oxidation
Oxidizing Atmosphere
Oxygenation of the Earth’s Atmosphere
Precambrian
Red Beds
Sedimentary Rock
Shale
Sulfate Minerals
Sulfate Reducers

Sulfate Reduction
Sulfidic Oceans
Sulfur Cycle
Terrestial Analog
Trace Elements
Trace Metals
Transition Metals and Their Isotopes

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