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A SYMPHONY OF ELECTRONS

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The concept of oxidation as the process that turns iron metal into rust is familiar to all of us. We might be equally familiar with reduction, the "reverse" of oxidation, by which iron metal is produced by heating iron ore with coke in a blast furnace. Rusting and smelting of iron are just two examples of reduction–oxidation ("redox") reactions. As one species (e.g., the iron ore) becomes reduced, so the other (e.g., the coke) becomes oxidised. In redox, there is always something being oxidised and something else being reduced; it's the yin and the yang of geochemistry, as the guest editors of this issue of *Elements* refer to it (cover).

Redox, despite the name, is not just about oxygen: what really matters is the transfer of electrons from one species to another. In this view, the loser of electrons becomes oxidised, and the gainer of electrons becomes reduced. Ultimately, redox is about moving electrons from one place to another. In the solid Earth, over geological time, electrons have flowed from the oxidised surface to the reduced core, but the path that they follow is far from straightforward. Charting the movement of electrons through and between Earth's various geochemical reservoirs is at the heart of this issue of *Elements*. What emerges is a symphony of electrons migrating, stalling, and even changing direction as our planet evolves. In effect Earth's "redox engine" is a kind of geological map: not of strata, but of electrons.

Earth scientists have long been fascinated with maps, the business of making data visual. In that sense, mapping electrons is geological business as usual. It is just over 200 years since that most celebrated of geological maps, *A Delineation of the Strata of England and Wales with part of Scotland*, was published by William Smith, a blacksmith's son from Oxfordshire (UK). Smith, almost entirely self-educated, trained as a surveyor. While overseeing construction of the canal network that underpinned the nascent industrial revolution, Smith recognised that rock strata could be correlated from one canal trench to another and that those strata could, potentially, be extrapolated underground. By this means, he could anticipate the subsurface geology, notably the extent to which seams of coal, and other valuable commodities, might lie at depth. The business of first making and then selling his map broke Smith physically and financially. Just four years after completing his map in 1815, he found himself in a London debtor's prison, overcome by exigent creditors and unable to capitalise on the anticipated demand for his map.

In a popular retelling of Smith's life, Simon Winchester's 2001 book *The Map that Changed the World* suggests that Smith's nemesis was George Bellas Greenough, then President of the Geological Society of London. Unlike Smith, Greenough was an educated man (Eton College, no less). Greenough's *Geological Map of England and Wales* became available in 1820, just in time to greet Smith on his release from prison. Whether its imminent publication played any part in Smith's demise is a matter of keen debate, but it certainly makes for a good tale. For Smith, at least, there was a redemptive ending. Shortly before his death in 1839, he was recognised by the self-same Geological Society of as the inaugural recipient of the Wollaston Medal, the society's highest honour.

FIGURE 1 Rodney Harris' elemental ("redox") version of William Smith's map. Copyright Rodney Harris. Reproduced with permission.

William Smith is one of science's unsung heroes, rarely mentioned in the same breath as those luminaries as Charles Lyell or Charles Darwin, contemporaries in the quest to understand geology, or Michael Faraday, poster-child of the Royal Institution, or Sir Humphrey Davy, a scientific rock star long before Brian May. Yet Smith's achievements, from humble beginnings, are no less remarkable.

To celebrate the bicentenary of Smith's map, Bristol-based sculptor Rodney Harris began work on a contemporary version. He came up with the idea of an elemental geological map, replacing the coloured inks of Smith's original with pigments fashioned from the appropriate ground-up strata. The resulting map (FIG. 1) reveals a landscape stripped bare, denuded of its anthropogenic and biological clutter. And in this, it is the colours that reflect the redox state of the rocks themselves, from the dark grey of reduced coal, to the reddish brown of oxidised red beds and clays. But the overwhelming impression is of a profoundly beige country beneath our "green and pleasant land".

In 2015, Bristol University (UK) held a series of four public lectures on different aspects of geological maps, from the history of William Smith's own effort, to the modern mapping of Mars using the *Curiosity* rover. Almost 1,000 people attended the lectures, testifying to widespread public interest in the Earth sciences, and the enduring power of geological maps. Reading this issue of *Elements*, it occurs to me that an electron map of the Earth would have made a welcome addition to that theme.

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