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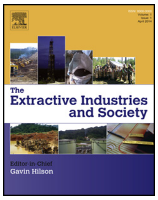

Review article

A historical geography of rare earth elements: From discovery to the atomic age

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ABSTRACT

This article presents a historical geography of rare earth elements from their discovery to the atomic age with a focus on the period between 1880 and 1960 in order to lend greater depth to the growing body of scholarship on the relationship between rare earth elements and global political change. Drawing on archival and field research undertaken in the United States, China, Brazil, and Germany between 2011 and 2014, this article advances the following argument. Rare earth elements, and the production of geological knowledge about them, have entangled with contentious politics since their first industrial applications in the late 19th century. The historical geography of rare earth exploration and extraction is defined by a fundamental tension between the military-industrial necessity of these elements and the hazards associated with their production. This tension played a definitive role in international colonial, Cold War, and atomic politics.

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1. Introduction

The international community was made aware of importance of rare earth elements in 2010, when China allegedly halted exports amidst a territorial dispute with Japan. At the time, China produced 97% of the global supply of rare earths, which are essential for a diverse and expanding array of communications, energy, information, and military technologies. Research and analyses have since proliferated on this important topic (Humphries, 2013; de Boer and Lammertsma, 2013; Wübbeke, 2013; Biederman, 2014; Hurst, 2010; Phua and Velu, 2012; Rauer and Kaufmann, 2015).

In historical terms, the majority of the academic literature focuses on the last decade and a half, while the geographical focus is overwhelmingly on China, Australia, and the United States. This makes sense, as the two largest sources of rare earth elements for the past 50 years have been located in Mountain Pass, California, and Bayan Obo, Baotou, Inner Mongolia, while the mine at Mount Weld in Western Australia has emerged as an important new site. However, some have erroneously attributed China's rare earth

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monopoly to geological determinism: that China possesses more rare earth elements than any other country is a stubbornly popular fiction in contemporary commentary (Wang, 2010; Lin, 2012; Xie, 2013; Yan et al., 2014). While the consensus in the contemporary literature is that China's production quotas and export controls 'politicized' rare earth elements, this article explains that in fact, the political life of rare earths began well over a century ago, with their earliest commercial applications and subsequent expansion of knowledge about their material properties and geological incidence.

The article presents an international historical geography of rare earth elements between 1880 and 1960. It was during this period that applications gradually began to expand as diverse state and commercial interests sought these elements ever further afield in the contentious times defined by colonial, atomic, and Cold War politics. However, it was not until the 1960s, with the rise of the Mountain Pass mine in Southern California that a period of relative calm and stability settled around the production of rare earths. Because the Mountain Pass era (1960–2000) is often positioned as the historical reference point against which contemporary rare earth politics are contrasted, this article focuses on the preceding eras in order to lend greater depth to the small but growing body of scholarship (e.g., Kiggins, 2015) on the relationship between rare earths and international political change over the course of history.

The analytical approach utilized herein is concerned with historical human–environment relations in terms of how past geographies influence those of the present. Such an approach reveals that the 2010 emergence of rare earths as important elements of international politics is more accurately characterized as a *re*emergence after decades of relative calm maintained first by US, and subsequently by China's *de facto* monopolies over mining and processing. Just as rare earths are at the center of several key 21st century geopolitical disputes, a historical geographical analysis reveals that the production of scientific knowledge about these elements has entangled with contentious politics since the end of the 19th century. During the period examined herein, various state and industrial actors undertook to explore and exploit these elements in ways that served broader territorial agendas, which had to contend with imperatives to secure these strategically vital elements while sequestering the hazards generated by mining and processing.

Each theme is explored herein. Section 2 defines the elements and the conditions of their discovery. Section 3 explains the physical properties of rare earth elements as they occur in Earth's crust and introduces the politics of geological knowledge production. The fourth examines the role of rare earths prospecting, research, and extraction in global politics from 1880 to the 1960s. Because developments in the political life of rare earths are diverse and overlapping, the histories are examined as several overlapping periods rather than in discreet chronological sequence. The article concludes its history where most begin: with the rise of US dominance of rare earth production that lasted until the end of the 20th century.

2. Discovery and classification

'In a way,' writes Abraham (2011, 101), 'it begins with semantic confusion.' Rare earths are not rare; the name is much less indicative of their actual qualities than certain assumptions made at the time of their discovery. In 1788, a miner in Ytterby, Sweden, found a strange black rock. It was identified several years later, in 1794, as a new kind of 'earth,' which is an archaic reference for acid-soluble elements (Rowlatt, 2014). It was later found to be a mineral consisting of cerium, lanthanum and yttrium in iron ore. Since such elements had not been found anywhere else, they were presumed to be scarce. Hence the name, *rare earths,* which refers primarily to the 15 elements in the lanthanide series ranging from lanthanum (atomic number 57), to lutetium (number 71). The implication of rarity has legitimated the ruthless pursuit and capture of these elements over the past century, and perhaps that is why the antiquated name persists over a 125 years after this misnomer was identified.[1]

The elements that are included with the lanthanide series in reference to rare earths changes over time: during the race to build the nuclear bomb, thorium and uranium were also referred to as rare earth elements because of their close affiliation and frequent geological coincidence. Currently, scandium and yttrium are also counted as rare earths, although they are found elsewhere on the periodic table: atomic numbers 21 and 39, respectively. Therefore, at present, *rare earths* refers to a group of 17 chemically-similar elements comprising about 17% of all naturally occurring elements (Cardarelli, 2008; Goldschmidt, 1978; Beaudry and Gschneidner, 1974; Liu, 1978).

Because of their exceptional magnetic and conductive properties, this family of soft, ductile metals is essential to an expanding array of high-technology applications fundamental to globalized modernity as we know it. There is no single 'rare earth market' to speak of, but rather, multiple markets for the 17 elements with widely divergent availabilities and applications. For example, erbium, which turns pink when oxidized, lends its hue to rose-colored glassware (Hammond, 2000) while also acting as an amplifier in fiber optic cables, which is critical to the functioning of global communications networks (Becker, 1999). The uses of neodymium are likewise wide-ranging. It is used to make permanent magnets in wind turbines, computer hard drives, and electric vehicles (Zepf, 2013), and it is also used to evaluate and predict the severity of volcanic eruptions (DePaolo, 2012). This gives rare earths an air of ineffability—they are seemingly everywhere, but in quantities too minute to quantify compellingly. The nature of their applications, like their geological incidence, is both ubiquitous and dispersed.

3. Geology, territory, and power

Rare earth deposits are borne of intricate geological processes that begin in Earth's mantle. They are formed in comparatively rare alkaline magmas, which possess sufficient iron and magnesium to support the coalescence of rare earths and related elements such as thorium and uranium into minable concentrations.[2] As the magmas go through repeated stages of heating and cooling, a process called fractional crystallization begins in which certain elements solidify as the temperature drops below their melting points. The elements that do not solidify during initial cooling phases are called incompatible elements. The critical feature of alkaline magmas is that the high iron and magnesium content facilitates the formation of relatively stable lattice structures that cradle the incompatible elements which ever-so-slowly solidify into concentrations of rare earth elements, niobium, uranium, and thorium. The material coincidence between rare earth elements

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[1] 'Until the year 1885, though by that time the scientific interest of the group had been fully demonstrated by the discovery of several new elements, it was supposed that the minerals were almost entirely confined to a few scattered localities in Scandinavia and the Ural mountains. In that year Dr. Auer von Welsbach announced his application of the rare earths to the manufacture of incandescent mantles. Immediately there was a great demand for raw material for the preparation of thoria and ceria. The agents of the Welsbach Company visited all the important mining centers of Europe and America, intent on a search which shortly made it clear that the metals of so-called "rare earths" are really quite widely distributed in nature,' (Levy, 1915, 2).

[2] For the sake of simplicity, I am describing the formation of a bastnasite Iron-REE-Th deposit here, such as those found in Bayan Obo, Baotou, Inner Mongolia in China and Mountain Pass, California, in the United States.