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Rare earth elements: Development, sustainability and policy issues

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ABSTRACT

Rare earth elements are essential to modern life as we know it. With their exceptional magnetic and conductive properties, they enable the hardware of contemporary life to be faster, lighter, and stronger. Since the 2010 crisis precipitated in part by China's then *de facto* monopoly over rare earth production, diverse actors across the globe have pursued multiple and sometimes conflicting measures to transform the industry. These include efforts to open new mines, lower prices, mitigate social and environmental harms, curtail black market activity, identify substitutable elements, and achieve national-level supply security. These diverse efforts intersect with broader geopolitical, historical, and cultural struggles around the world. The outcomes of these efforts vary, though arguably few have generated intended results. Several years after the global (re)awakening to the importance of rare earth elements and the hazards associated with their production, the relationship between its industries and society, broadly defined, remains troubled in practice, poorly-conceived in policy, and under-examined in the social science literature. This special issue convenes emergent social science research into some of the development, sustainability, and historical issues surrounding rare earth elements in different times, places and sectors across the globe.

1. Introduction

Rare earth elements are essential to modern life as we know it. With their exceptional magnetic and conductive properties, they enable the hardware of contemporary life to be faster, lighter, and stronger. Since the 2010 crisis precipitated in part by China's then *de facto* monopoly over rare earth production, diverse actors across the globe have pursued multiple and sometimes conflicting measures to transform the industry. These include efforts to open new mines, lower prices, mitigate social and environmental harms, curtail black market activity, identify substitutable elements, and achieve national-level supply security. These diverse efforts intersect with broader geopolitical, historical, and cultural struggles in different sites across the globe, directly and indirectly enlisting rare earth mining in issues as diverse as the ongoing US-led occupation of Afghanistan to the defense of Indigenous land use rights in the Brazilian Amazon. The outcomes of these efforts vary, though arguably few have generated intended results. Several years after the global (re)awakening to the importance of rare earth elements and the hazards associated with their production, the relationship between its industries and society, broadly defined, remains troubled in practice, poorly-conceived in policy, and under-examined in the social science literature.

This special issue convenes emergent social science research into some of the development, sustainability, and policy issues surrounding rare earth elements in different times, places and sectors across the globe. The importance of these elements transcends sectors and disciplines. The complexity of their geological incidence, historical geographies of production, social importance, and contemporary applications also defies a unified global analysis of rare earth industries and society.

This is due to the importance of rare earth elements to many critical technologies. Because they are critical to the technologies of global communications, transportation, medicine, energy generation, surveillance and militarism, questions surrounding access and applications are geopolitically charged. The quest for rare earth elements has been entangled in the defining territorial struggles of the past century, because control over these elements has frequently been understood as control over one's development destiny. Furthermore, rare earth mining and processing continues to be done in an environmentally destructive way, which generates conflict in current and prospective mining sites.

Conventional theories on global resource geopolitics would explain the complex political lives of rare earth elements as a result of scarcity, which, when combined with mere accidents of geology, would be sufficient to explain efforts to mine them in socially and environmentally sensitive places. This logic contends that prospectors look for rare earths in remote places such as North Korea, Afghanistan, Greenland, and colonial Africa simply because there are no other options. This logic absolves us of our responsibility to critically analyze the problematic *status quo* of rare earth elements.

This logic does not withstand basic empirical inquiry into the

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contemporary political economy of rare earth elements. Rare earths are not rare, so the tendency for them to be invoked as causes for conflict in scholarship, policy discourse and popular culture says more about our antiquated resource assumptions than about the objective reality of rare earth elements on Earth. Most of these elements are as abundant as copper or lead. Annual global demand has yet to surpass annual supply, which fluctuates between the relatively modest 120,000–140,000 t. Despite the political intrigue that capitalizes on the myth of rarity, the global rare earth economy has in fact been characterized by oversupply and insufficient demand. By any measure—geological, economic, or political—rare earth elements are not rare.

Instead, what is rare about these elements are the places where it is politically acceptable to mine and process them in a cost-effective manner. Rare earth elements tend to coincide with other elements that are harmful to human health when dug out of the ground and pulverized into fine dusts: heavy metals, arsenic, and fluorite, among others. Add to this the acids needed to separate elements from their parent material, and the result is a large volume of waste that is expensive to effectively control. This has led to a preference for mining in sites where local populations have limited power of refusal or cannot hold the mining industry accountable. Environmental violations resulting from irresponsible waste management practices have plagued the sector, and generated justifiable resistance in communities neighboring proposed mining sites.

Not only are rare earths abundant in the Earth's crust and in the global market, much less controversial methods for maintaining a steady global supply are readily available. These are flex mining and recycling. Flex mining refers to the practice of reprocessing the tailings from other mines or industrial production activities for rare earth elements (Knapp, 2016). Efforts are underway to extract high purity rare earth oxides from a niobium mine in Brazil, and from coal ash in the United States. Rare earth elements are also abundant in phosphorus, silver, and lead mines in different parts of the world. Reprocessing existing mine wastes for rare earths and other useable elements would fix multiple problems at once. The accumulated wastes in aging infrastructure from 20th century mining operations, some of which were never built to effectively contain toxic waste, present a persistent and growing problem for the local and national contexts in which they are located. Opening new mines is risky and costly. It poses economic risk for investors, it poses political risks for local and national governments backing potentially controversial projects, and even the most carefully-managed operation poses environmental health and safety risks for neighboring communities. Reprocessing existing mine wastes would reduce the overall footprint of former mining operations. This would facilitate local environmental remediation efforts while also negating the need to open new mines. The outlook for flex mining is promising but unproven on an industrial scale.

A similar situation characterizes recycling. Annually, less than 1% of rare earth elements consumed are recycled, meaning that we are accumulating untapped stockpiles in our electronic waste. Although it is, admittedly, challenging to implement a recycling program that requires the collection of items as diverse as smart phones and rockets, it is hardly impossible. Meanwhile, scientific breakthroughs in recycling methods are largely ignored in policy due to a lack of political will. This state-of-affairs allows the faulty logic of scarcity to prevail, which supports the misguided quest to open up new mines around the world. The notion that opening new mines is the best or only reasonable way to acquire rare earth elements is antiquated. It is a markedly 20th century mentality, which grew out of the colonial extractivist regimes of the preceding four centuries. Our technology has changed such that for the first time in known history, flex mining, reclamation, and recycling can feasibly replace mining as primary sources for critical minerals. But investors, policy-makers, and the market have been slow to adapt, confirming that the past and present of rare earth industries are inseparable from their social context.

In a context of geological abundance and amidst exciting technological potential, efforts to mine rare earths in remote, conflict-prone, or sensitive locations continue. North Korea, Greenland, Afghanistan, Madagascar, and the Amazon Rainforest are just a few of the places that have made headlines in recent years as the next 'jackpot' in a global quest to find the next source of these 'critical' materials. The fact that we have the technology and the lucky geology to produce rare earth elements in a sustainable and conflict-free manner; yet, we are overwhelmingly failing to do so, indicates that the contemporary geography of rare earth prospecting and production is driven by secondary interests which are sometimes only marginally related to rare earth elements.

Understanding these interests is important to building a more efficient, sustainable, and just rare earth economy. To move away from the violent political economy of rare earth elements requires a measure of global coordination that pessimistic commentators say is not possible. Pessimism is easy because it demands nothing. By doing nothing and discouraging others, pessimists are proven correct when change fails to happen. Alarmism is similar. It may take slightly more energy to rearrange a partial understanding of the global rare earth economy into yet another variation of 'the China threat' to generate alarm, but the intellectual demands are equally as light. Neither pessimism nor alarmism require an in-depth understanding of the historical and contemporary complexities of the rare earth sector, while both preclude the hard work of formulating and coordinating collaborative solutions.

A constructive approach to the contemporary rare earth problem is to examine specific aspects of related development, sustainability, and policy issues. There are two ways to do this. The first is to look at in-depth case studies from specific times, places, and sectors in order to clarify the complexity, bit by bit. The second is to examine the ways in which the persistent confusion is useful for political, geopolitical, and economic agendas. The articles in the special issue address the first, and this introduction approaches the second.

This introduction to the special section of *Extractive Industries and Society* proceeds as follows. The second section presents a broad overview of some of the scientific, public, and popular literatures on rare earth elements since the 2010 crisis. The third section presents one illustrative example of problematic relationship between rare earths and geopolitics. The final section introduces the articles in this collection.

2. The 2010 crisis and subsequent publications

In late 2010, the world awoke to its dependence on China for 97% of the global supply of rare earth elements. Although production had migrated from the West to China in a gradual process over the latter two decades of the 20th century, it had been largely ignored outside of the sector. For nearly a decade, no one complained about the concentration of this dirty and dangerous industry in China's hinterlands, until rare earth elements featured in a geopolitical dispute between Japan and China over the Diaoyu/Senkaku Islands. The Japanese coast guard detained a Chinese fisherman who strayed too close to the islands, which was interpreted in Eastern China through the lens of WWII atrocities. Frustrated with what they viewed as Beijing's slow response, a handful of port workers and officials decided to take matters into their own hands by reminding Japan of its economic dependence on China. They held up shipments of rare earth oxides bound for Japan, which temporarily disrupted some of the flow of these commodities from China to Japan. This was, by and large, an inconsequential event that blew up into a market panic and a political crisis after the New York Times ran stories suggesting that China had embargoed rare earth shipments to Japan (Bradsher, 2010; Bradsher and Tabuchi, 2010).

Although it was not the first story published on China's rare earth sector (Bradsher, 2009a,b; Hilsum, 2009) this story brought a rude awakening to global dependence on China for critical materials. The market responded with a panic: prices for some elements increased by as much as two thousand percent. In the unfocused and frantic moments that followed, several inaccurate conclusions were drawn on the

nature of the global rare earth economy. Among them: making the obvious assumption that rare earths are in fact rare, people concluded that because China produced 97% of the global supply, it must then also possess most of known global deposits. Others presumed that the disruption in exports to Japan indicated that China intended to embargo rare earth exports to place the rest of the world in a 'stranglehold' (Anthony, 2010). These assumptions drew on the market panic as evidence that rare earths were actually scarce. Menaced by China, it seemed that the rest of the world faced no choice but to mine rare earths wherever new deposits could be found.

There was a considerable lag before reasonable and empirically-based analyses could cut through the furor (Massari and Ruberti, 2013), but the dystopic fantasy of China controlling the world through its monopoly over a critical resource has thoroughly lodged itself in the popular imagination, with consequences felt from Malaysia to Madagascar to the Moon (Klinger, 2017). These consequences generated new literatures in the physical sciences, social sciences, and popular culture.

2.1. Physical sciences

Rare earths have been the subject of intensive research in the sciences since their discovery in 1794. Over the 20th century, major strides were made in understanding the chemistry and geochemistry of rare earth elements on Earth and in the cosmos, based on analyses of rare earth elements in meteorites (Henderson, 2013). Research into the alloying possibilities of certain rare earth elements to other metals has been ongoing since the 1930s, with recent focus on producing lighter alloys for vehicle and construction applications in order to reduce fuel needs (Bohlen et al., 2010; Hirch and Al-Samman, 2013), and ongoing research into the magnetic properties of the elements in photonics and nanotechnology (Escudero et al., 2017; Iizuka et al., 2017; Farghali et al., 2018).

The supply concerns evoked by the 2010 crisis stimulated four primary branches of new research into rare earth sciences: options for substitution, improved separation techniques, recycling, and secondary sourcing. Substitution efforts found that other elements could replace rare earth elements in certain applications (Ulmer et al., 2015; Lewis et al., 2014; Pavel et al., 2017). Although this is useful, in some cases it simply shifts to the environmental, social, and geopolitical tensions from the rare earth sector to another mineral commodity. Recognizing this, researchers have worked on developing motors and magnets that function without rare earth elements at all, in order to phase them out entirely from energy-critical technologies (Mostafa and Medraj, 2014; Lewis et al., 2014). Others have been working on improving separation techniques in order to enhance the efficiency and lower the cost of rare earth processing (Jordens et al., 2013; Huang et al., 2015; Xia et al., 2014).

Simultaneously, researchers across the globe have been working on improving recycling techniques in order to be able to reclaim rare earth elements from electronic waste (Walton et al., 2015, Binnemans et al., 2013, Lixandru et al., 2017, Kamimoto et al., 2017, Wang et al., 2017, Verrax, 2015). Tackling rare earth recycling requires building effective electronic waste collection systems, with differentiated responsibilities for producers and consumers (Zeng and Li, 2016). This would allow for the reclamation of a many other valuable elements aside from rare earths (Shuva et al., 2016), and holds considerable economic promise (Corder et al., 2015).

As noted above, an important fourth branch of development of the rare earth sciences is recovery from secondary resources such as existing waste from other mines. The US Department of Energy awarded $20 million to a consortium of researchers at Duke University and University of Kentucky to extract rare earth from coal ash (Taggart et al., 2016). Others have identified the potential for generating abundant rare earths (and other useful materials) in bauxite and kaolin residues, and other industrial wastes (Binnemans et al., 2015; Yang and Bin, 2013; Dehaine and Filippov, 2015).

2.2. Social sciences

Research in industry and physical sciences intersects with social science research at the point of practical matters: the politics and practices of rare earth prospecting, sourcing, production, distribution, and supply chains. Although it is still early to assess the extent to which the diverse research, policy, and institutional actions stimulated by the 2010 crisis will constitute a turning point, if any, in the global political economy of rare earth elements, several initial assessments have been completed (Eggert et al., 2016; Kiggins, 2015). Much of the research has been driven by new policy mandates, which emerged following the 2010 crisis and reflected a greater public awareness of the elements and their importance. Rare earths were then officially coded with a number of exigent adjectives: they became 'strategic,' and 'vital' materials crucial to 'security,' 'technology,' and 'the future.' This designation facilitated the formulation of government policies to support the sort of research presented in the previous section, and generated new research into the global, national, and local dynamics comprising the contemporary rare earth situation.

Most of the post-2010 crisis research only began to be published in 2012. It has been critical for clarifying the origins, significance, and nature of the 2010 crisis in particular and the global political economy of rare earths in general. Historical research found that rare earth prospecting, mining, and production have co-evolved with international political struggles since the1800s, suggesting that there is nothing particularly new about the 2010 crisis (Klinger, 2015b). Others noted that despite the geopolitical hype over rare earth elements, it has been a relatively a minor factor in changing industrial and policy practices (Wübbeke, 2013). To the extent that changes have occurred, they have followed the 20th century mold of building stockpiles and opening new mines. The global industrial geography continued to be driven by capital and environmental cost concerns despite heightened international attention to the sector (Long et al., 2012; Massari and Ruberti, 2013; Apergis and Apergis, 2017). At the same time, the heightened global awareness of rare earth elements catalyzed much needed conversations around improving industry practices to reduce social and environmental conflicts (Ali, 2014), though conflicts have continued at extant and prospective mining sites as environmental concerns have been inadequately addressed (Phua and Velu, 2012; Carver, 2017; SLSM, 2014; Fischer, 2015).

The rude awakening precipitated by the 2010 crisis stimulated an unprecedented wave of interest in the supply chains and life cycles of rare earth elements. Some examined these dynamics out of concern for the environmental and health impacts of rare earth mining and processing (Klinger, 2015a; Pagano et al., 2015; Sprecher et al., 2014; Carpenter et al., 2015; Weng et al., 2013). Others focused on mitigating the risks of future supply disruptions (Keilhacker and Minner, 2017; Stegen, 2015; Mancheri, 2015), and still others capitalized on the moment to develop proposals to "green" the rare earth supply chain (Rauer and Kaufmann, 2014). Despite a number of feasible proposals to improve the sustainability of the rare earths lifecycle (McLellan et al., 2014), there remains a considerable gap between theory and practice, due to policy and market failures. Governments thus far have failed to provide sufficient certainty to support investments in environmentally sound rare earth production, while major downstream buyers have opted not to purchase more sustainably produced rare earth elements.

Because rare earth elements are critical to life as we know it, they present rich and as yet, largely untapped, potential for fertile social science research. Beyond policy analysis and supply chain concerns, the integration of these elements into everyday life in ever more intimate and mundane ways requires further analysis.

2.3. Popular culture

The threat posed by China's monopoly over critical resources became a favored plot device in fiction, television, and video games in the

aftermath of the 2010 crisis. A number of novels elaborated dystopic fantasies of a world on the brink of war because of China's economic statecraft (Asher, 2015; Bunn, 2012; Besson and Weiner, 2016; Sellers, 2016). The public imagination was primed, in part, to interpret the 2010 crisis in these terms by James Cameron's 2009 film *Avatar*, in which a corporate giant scoured other worlds in pursuit of a fictional element rather obtusely called *unobtainium*. Early in the film, the character playing the corporate manager fondles a lump of shiny silvery metal that closely resembles a refined rare earth element like lanthanum or europium. As he rolls it over in his fingers, he explains that the exceptional conductive properties of this element justifies the expense of conquering new worlds, invading the territory of indigenous people, and wreaking all manner of social and environmental havoc (Cameron, 2009). *Avatar* broke several records for box office sales and other revenues. By late 2010, millions had seen the film.

The 2010 rare earth crisis fit perfectly into this popular sense of hyperbolic resource geopolitics. The press was quick to draw parallels between the *Avatar* plot and China's control over rare earth elements (Jones, 2010), launching a dynamic in which fiction and fact blurred in evolving public awareness of rare earth elements. The 2012 release of the first-person shooter video game *Call of Duty: Black Ops II* was built with the input from architect of the Iran-Contra scandal, Oliver North and from Brookings Institute's future warfare expert Peter Singer (Stuster, 2012). The plot takes place in 2025, when China halts exports of rare earth elements to the US and a futuristic Cold War ensues. Reviewers raved over the "eerie similarities" to real world politics, while Fox News speculated that the "game could reshape real warfare." It went on to say:

> "In terms of influence, 'Call of Duty: Black Ops 2' will have a huge advantage over the military and defense think tanks, because as video game entertainment it reaches far more people than any workshop, report, or book ever will." (Fox, 2012).

In this excitement over the impact of the video game, which broke all sales records for its time, a concern for the truth of the rare earth situation was lost. Instead, the public was (mis)educated to think of rare earth elements as a plot point in a larger drama leading to inevitable war because China blocked rare earth shipments. This trend of expecting fiction to shape policy was further manifest in 2014. The popular Netflix series, *House of Cards,* featured a tense episode in which US and Chinese business tycoons sought to manipulate US-China diplomatic negotiations to facilitate the leasing of a Chinese rare earth refinery to a US billionaire. Rare earths were a minor plot point that were used to dramatize the confluence of geopolitical, private, military, and diplomatic tensions in US-China relations (Willimon, 2014). The series fictionalized the nature of US dependence, helping to cement the misconception that China produces most rare earth elements because it possesses the majority of global reserves. By 2014, plenty of research had emerged that contradicted this, but lobbyists lamented that policymakers were not inspired to greater action by the episode (Editors, 2014).

It is worth repeating here that China never embargoed rare earth elements. Strictly speaking, an embargo is an official blockage of all commodities to an enemy state in wartime. At most, a few shipments were upheld over a period of weeks from a single port. This minor disruption would likely have passed unnoticed if the New York Times had not broken a story to a public reeling from multiple economic, political, and environmental uncertainties in 2010. Without a prior knowledge base, people made the obvious, but incorrect, conclusion that rare earths were rare, that China produced most of them because China possessed most of them. The story has since been sorted out among specialist audiences, but the impact of this collective public shock has remained.

The popular culture narratives that emerged around the rare earth crisis—and the way they continue to be leveraged by opportunistic actors—inflamed existing anxieties in the US over China's rise. These anxieties are found across the ideological spectrum, with right-wing policymakers insisting on rare earths as yet another cause for war with China, and left-wing commentators blaming decades of poor industrial policy for allowing the US industry to migrate overseas (Ting and Seaman, 2013; Krugman, 2010). In retrospect, it is now possible to discern a pattern of collective mythmaking with respect to China for politically expedient ends that bear a loose relationship to the truth but are largely divorced from reality. CK Lee describes this uneasiness around China's growing global influence as a specter that haunts the West (Lee, 2014). Fictionalizing these anxieties may have served an important psychological and intellectual purpose of allowing a troubled public to run emotional simulations of uncertain futures (Oatley, 1999). Psychologists would explain the intense popular interest in *Avatar, House of Cards,* and *Call of Duty,* in terms of "information-seeking behavior" (Case and Given, 2016) In the most innocuous sense, then, these fictionalized and dystopic accounts of China's role in global rare earth politics served as a way for people to make sense of a confusing present and a profoundly uncertain future.

The consensus among psychological researchers holds that fiction can exert a more powerful cognitive effect than fact, because of its dual effects on thinking and feeling: two decades of research demonstrates "that 'facts' from fictional readings are quickly incorporated into real world knowledge" (Case and Given, 2016, 135). Even though one part of the brain may know fiction when it encounters it, other parts of the brain learn it as information. Absent subject-specific knowledge, the fiction then stands in for the information that is lacking, with discernable effects on behavior and decision-making. This finding is supported by theory across the social sciences. Cultural theorist Stuart Hall (1992) observed that discourses—in this case, that China holds the world in a rare earth stranglehold, leaving extreme measures as our only option to restore resource security—do not necessarily need to be true in order to influence how people interact with the world and with each other.

3. Recent developments: an illustrative example

This has been manifest in the rare earth sector. Myths exercise a powerful force over investors, policymakers, and commentators intent on seeing rare earth elements as the lodestone for whatsoever their desired outcome may be: rare earths have been hailed in Burundi, Brazil, and the state of California as the salvation of an ailing economy. In Greenland, Argentina, and North Korea, they have been invoked as the key to development and influence for frustrated state powers, or as noted above, as the next cause for war in the US and China.

Perhaps the greatest manifestation of the confusion of fact and fiction lies in the proposal of Blackwater founder Erik Prince to privatize the US-led war in Afghanistan with 'security contractors,' whose operations will be financed by rare earth mining. Prince, whose firm has been disgraced by the illegal massacres perpetrated in Iraq (Fitzsimmons, 2013), has advocated for "An East India Company approach" in the *Wall Street Journal*, in which private US firms take over US military occupation in exchange for commercial rights (Prince, 2017). In a briefing to the White House in mid-2017, Prince invoked familiar tropes of the China threat, and the scarcity of rare earth elements as undermining US industrial capacity.

What is actually happening here is that Prince is using rare earth elements as a plot point in a personal ambition to establish an empire in Central Asia. This is not the first such attempt with respect to Afghanistan (Skinner, 2015). In this pitch, the operative myths circulating in popular culture have combined with an enduring fantasy that characterizes the mining sector: the lucky prospector with sufficient appetite for danger could find the next mother lode and be remade as a mining magnate (Tsing, 2005). Even if the rare earth reserves in Afghanistan are as great as some speculators claim, there is no market to absorb the additional output, and China poses minimal threat. Global supply has outpaced demand for the past several years, and since 2005, China has been implementing a series of reforms in order to reduce its

global share of rare earth production (Klinger, 2017; Chen, 2010, 2011). The circulation of gripping, fictionalized accounts to further megalomaniacal personal agendas is perhaps best described by what contemporary philosopher H.G. Frankfurt (2005) has called the most salient feature of our age: "bullshit." This is not so much untruth as a lack of concern for the truth.

This helps explain the Blackwater proposal. Even though the founder has successful business interests in China, his plan to *Avatar*-ize Afghanistan is cynically pitched as a way for the US to mitigate China's purported threat in the rare earth sector while supplying the US' high-tech manufacturing supply chain (Roston, 2017). Scholars and policy-makers concerned with the US manufacturing supply chain have been consistent in their message that the problem is not that it is lacking rare earths, but rather that the industrial capacity that comprises a US supply chain has disintegrated over the past 30 years (Fifarek et al., 2008). But Prince's proposed arrangement requests that the United States grant him the power and authority of a British imperial governor over the territory of a sovereign state. In this arrangement, he would be entrusted with the use of violence to secure resource extraction in Afghanistan, coordinated through the US's global surveillance network in collaboration with Chinese security companies. It should be clear that Prince's proposed solution does not match the problem, even according to the terms in which he defines it: that US manufacturers are deprived of rare earths by China, and Afghanistan needs to develop. Instead, the proposal would enable Prince to profit from selling rare earth elements to China, which has the greatest institutional capacity and purchasing power in the rare earth sector, while sharing US intelligence to coordinate logistics with Chinese partners. The result would be a project to perpetuate US dependence on China's rare earth goods and the expropriation of the Afghani Government of its mineral wealth.

But the Blackwater proposal makes sense if one's knowledge of contemporary rare earth politics is shaped by the dystopic fantasies that pervade popular culture. This proposal is most likely to appear feasible if one has ignored the global rare earth market for the past five years. If that is the case, then it is conceivable that one would also lack the scientific and technological literacy to recognize that greenfield mining is an antiquated approach to acquiring rare earth elements. In other words, this proposal can only be proffered in ignorance, or out of an utter lack of concern for the truth. Bombastic proposals such as these threaten to overwhelm the prodigious body of scientific research dedicated to stable, secure, and sustainable rare earth production that minimizes social and environmental harms.

4. A note on the special issue

Those who are interested in a stable, ethical, and economically robust system of rare earth production and consumption have an uphill battle. We must not only continue to investigate the origins of our present moment on a global scale but must also effectively communicate the details of ongoing scientific breakthroughs to present the empirical evidence that demonstrates that just, secure, and sustainable rare earth production and consumption is possible. But in order to create the conditions of possibility for widespread adoption of key technological breakthroughs, we must also critically deconstruct the political economy and the history of rare earths. The uphill battle is to be fought with detailed and in-depth research into the complexities of rare earth elements.

This collection represents a humble but substantial offering toward that cause. It is neither a comprehensive overview of the global rare earth sector nor a complete compilation of the latest research by all scholars and scientists working on these issues. Rather, the five articles here are a rich sample of the geographical, theoretical, and sectoral diversity of rare earths research in the social sciences. This collection provides an in-depth look at the evolution of speculative investment in the rare earth market surrounding the 2010 crisis, explores ways to build confidence and reduce uncertainties in global value chains, and shows how the political life of rare earths has unfolded in three very distinct historical cases. Taken together, these articles shed new light on our contemporary moment.

Cox and Kynicky open the collection with a study of the rate of investment capital flows into the rare earth element junior mining market before, during, and after the 2010 crisis. The authors find that the majority of capital raised from 2006 to 2015 occurred during the crisis period from 2010 to 2012. Investors were moved by a host of factors, including media reports, international politics, stock prices, and political pressure to find immediate solutions to the 2010 crisis. Of the approximately 400 companies that were pursuing mining operations during that period, only two—Australia's Lynas Corporation, Ltd and the US' Molycorp, Inc.—achieved commercial rare earth production. Molycorp went bankrupt in 2015. Clearly, investment capital and ambition were insufficient in the majority of cases. The findings of this article invite further inquiry into the political, economic, and technological pressures that complicated the emergence of new players in the rare earth mining scene.

Machacek and Fold use a global value chain framework to uncover the complex relations between second and third-tier producers of rare earth magnets for the automotive industry in Europe and China. The authors find that European and Chinese firms compete for favorable relations with first-tier suppliers to automotive end-users. In this competition, they seek to control strategic information flows in order to advance their positions. This behavior yields new theoretical insights into the ongoing global economic restructuring processes unfolding in the less visible links in global rare earth supply chain. The findings of this article show the importance of human agency in economic processes, and propose new variables to the global value chain framework to account for this dynamic.

Bruun excavates the political life of rare earth elements in Greenland through a rich historical analysis of Danish uranium prospecting during the cold war. Drawing on archival research and fieldwork, this article illustrates how scientific knowledge production about rare earth elements and related materials represent an effort to order society according to an extractivist and developmentalist agenda within a context of global geopolitical turmoil. Theorizing state power through geological data production, the findings of this article show how politically contested visions for Greenland's future are entangled with imaginaries of its geological endowments. Scientific knowledge production delineates the possible horizons of state and colonial power, while the political cultures of the state delineate the actual conduct of scientific knowledge production. Through this dialectical relationship did Greenland's substrata transform from unknown to minable to the key to greater power as envisioned by Greenlandic and Danish elites.

Akiwumi and D'Angelo present a case study from Sierra Leone to show how the colonial past disrupts the present. The national government highlighted the importance of rare earth mining to national development in the 2012 Agenda for Prosperity, but this hardly constitutes the first engagement with the ambition. Drawing on documents from the British colonial office as well as contemporary primary source material, this article shows that the development of extractive interests cannot be understood in a linear fashion. Rare earth elements were catalogued during the colonial era, received no attention for several years, and then reemerged in a post-colonial landscape following the 2010 crisis. Through a case study of the titanium mineral sands industry, the paper elaborates concepts of resource making and resource taking to theorize the process through which Sierra Leone's minerals were transformed into resources to serve outside interests and expropriated from the country. Now, using a legal framework designed to facilitate colonial resource expropriation, the Sierra Leone government is struggling to exert control over geological endowments claimed by competing domestic and international groups. The article yields broader insights into the challenges faced by post-colonial and sub-Saharan African countries seeking to (re)enter the global rare earth economy.

Winstanley-Chesters provides a deep dive into a North Korean Documents Collection captured by the US armed forces during the occupation of Pyongyang in 1950. Through a close analysis of an unusually detailed body of topographical and cartographic documents, the author investigates how rare earth elements entered the political 'web of life' in North Korea's nation-building projects. Far from being inert objects, the author theorizes that rare earth elements became 'lively matter,' exerting influence over the developing social and political culture that characterizes contemporary North Korea. The findings of this article yield new empirical insights into North Korea's history of development, nation-building, and state survival, as well as theoretical insights into the agency of rare earth elements in elite dreams of utopian possibility.

The rare earth industry and associated science, technology, and policy co-evolves with multi-scalar social, cultural, and political processes. In order to build a sensible and sustainable rare earth future, we must understand our contemporary rare earth situation. Doing so requires taking a closer look at the diverse histories, complex market dynamics, and multiple value chains co-produced with rare earth elements. The five articles in this collection represent a contribution to this effort.

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