BEYOND STRIKES AND STORMS: REDUCING U.S. VULNERABILITY TO SUPPLY DISRUPTIONS OF DEFENSE-CRITICAL MINERALS

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By

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BEYOND STRIKES AND STORMS: REDUCING U.S. VULNERABILITY TO SUPPLY DISRUPTIONS OF DEFENSE-CRITICAL MINERALS

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ABSTRACT

Given China’s recent embargo of exports of rare earth minerals, concern for U.S. vulnerability to supply disruptions for defense-critical minerals is growing. In this study, I test my hypothesis that in practice a combination of economic, geographic, and political factors is usually necessary for minerals supply disruptions to affect the U.S. defense industrial base. In order to answer this question, I compare cases of four minerals – gallium, rhenium, tantalum, niobium – and rare earth elements, focusing from 2005 to the present. Each of these is identified in the 2008 National Academies of Science report *Managing Materials for a Twenty-First Century Military* as critical to military assets that will grow in importance in future warfare. Among these cases, I will compare the potential causes of supply disruptions in order to determine what factors are most important in signaling vulnerability. This initial study appears to confirm the importance of creating a suite of policy prescriptions that address a range of potential vulnerabilities. The next logical steps in building on this work include examining minerals exported from the Democratic Republic of Congo (such as coltan) and lithium, given growing concerns for the vulnerability of supplies from Bolivia.
The research and writing of this thesis
is dedicated to my family, colleagues, and classmates
who helped along the way.

Many thanks,
CHRISTINE L. PARTHEMORE
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I. INTRODUCTION

The United States is in the midst of a snowballing trade dispute with China. While this dispute has previously focused on tires and steel, the primary focus is now on rare earth elements, a class of minerals that are difficult to process yet critical to many high-tech applications.¹ China currently controls more than 90% of the world’s rare earth supplies, and is reported to be withholding exports and considering a reduction in its annual export quotas of these minerals. For its part, the Chinese government contends that it has not put any formal export embargo in place and that its plans to reduce exports simply reflect the need to meet the growing domestic demand for rare earths.²

In the United States, the ongoing rare earths conundrum is sparking protectionist attitudes, as some worry that import dependence is inherently a risk to the U.S. economy. Concern has grown to the point that Congress held hearings on the strategic importance of minerals. In the FY 2010 National Defense Authorization Act, for example, Congress required the Department of Defense to study and report on its dependence on rare earth elements for weapons, communications, and other systems.³ Indeed, it is important to explore the true nature of cases like the current China-rare earth minerals situation in order to understand whether each

¹ Rare earth elements are a class of minerals with similarly unique physical and chemical properties, including yttrium, lanthanum, neodymium, samarium, and europium. These minerals are not actually rare in nature; however, they are found in such small concentrations that extensive, precise processes are required to separate these minerals. Because of their unique properties – for example, some retain magnetism at extreme temperatures – these minerals are important in an array of modern technologies such as laser-guidance systems, telecommunications equipment, satellites, and permanent magnets used in jet engines. For a good overview on rare earths, see David Biello, “Rare Earths: Elemental Needs of the Clean-Energy Economy,” *Scientific American* (13 October 2010).
² Get article
case is unique or indicative of broader problems related to minerals policies. Supply disruptions can reduce price stability, create leverage for supplier countries, create competitive tensions among consumer countries, or otherwise negatively affect U.S. interests. Disruptions in supplies of some military-critical minerals can also damage defense readiness and place unanticipated strains on defense procurement budgets.

Vulnerability to minerals supply disruptions is not a new concern for the United States. Since the early 1900s, U.S. defense analysts and national policy makers have worried about U.S. vulnerabilities to supply disruptions of the minerals critical to manufacturing defense systems, from tanks and munitions to communications equipment. These concerns were heightened in wartime. Since World War II, the Department of Defense has stockpiled minerals and materials of strategic value to ensure access to these goods.

Today, however, the National Academies of Science reports that “The risk of supply interruption arguably has increased or, at the very least, has become different from the more traditional threats associated with the more familiar ideas of war and conflict,”

4 The defense industrial base in the modern era differs greatly from any previous time. During World War I and II, for example, governments counted on domestic steel production – and even civilian willingness to contribute scrap materials for reuse and recycling – for tanks and other equipment. In contrast, modern warfare relies on globalized and privatized supply chains rather than a primarily domestic (and often government-run) network. Much of today’s defense equipment is purchased directly from civilian vendors and is inherently dual use, designed to meet both

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civilian and military needs. Consider modern warfare’s dependence on computer systems, satellites, radar, and GPS. The same National Academies study notes that “The globalization of materials production and supply has radically changed the ability of the United States to produce and to procure materials vital to defense needs,” and that the stockpiling system is inadequate given today’s global supply systems. The question is: what factors should serve as warning signs, and what can policy makers watch for in order to better anticipate and mitigate mineral supply disruptions?

Identifying when and how mineral supply disruptions could affect U.S. defense industries is complicated both by often-long global supply chains and the nature of transactions. In some clear-cut cases, production at specific mines that produce large proportions of global supplies is halted by natural disasters or strikes. In blurrier cases, “disruptions” manifest as long contracting or legal delays (often intentional, for pricing or political reasons) or long lags in delivery. Whether the nature of the supply disruption is abrupt and clear, or long and uncertain, delivery times and prices on important defense equipment can rise significantly. Worst case scenarios extend beyond the availability and affordability of defense assets, in particular when minerals suppliers manipulate their export policies to gain political leverage over consumer countries – especially in times of war or other crises.

While U.S. policies often rely on individual factors to signal vulnerability, in practice a combination of economic, geographic, and political factors is often necessary for minerals supply

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6 I am indebted to contributions by Dr. Jennifer Sims and classmates Alison Leary-Miller, Samantha Kentis, Leah Kuchinsky, Joseph Caddell, Jennifer Greanias, Colin Reynolds, and Daniel Mahanty for comments and suggestions on this full paper, and in particular for their assistance in better defining this research question and for refining the chart on page 21.
disruptions to affect the U.S. defense industrial base. Minerals also differ in their production and consumption, which indicates that even when vulnerability to disruptions does boil down to a single factor, that factor is likely to differ across the range of defense-critical minerals.

In order to show this complexity, I will compare cases of four individual minerals – gallium, rhenium, tantalum, niobium – and rare earth elements. Each of these is identified in the 2008 National Academies of Science report *Managing Materials for a Twenty-First Century Military* as currently important for the smooth functioning of the defense supply chain and named as critical to those military assets likely to grow in importance for future warfare. For each, I will focus only on characteristics of the market since 2005. Within the past five years, two of these cases – rhenium and rare earth minerals – have involved supply disruptions or important threats of disruptions for the United States. I will also apply somewhat arbitrary thresholds for examining the factors for comparison, such as fewer than 3 suppliers controlling more than two-thirds of global supplies, and greater than 50% of known supplies located in a single country.

Among these cases, I will compare the potential causes of supply disruptions in order to determine what factors are most important in signaling vulnerability. Despite its history of dealing with this vulnerability, the United States remains less prepared for supply disruptions, price spikes, and trade disagreements than most experts realize. This vulnerability is likely to place critical national security interests and broader foreign relations at risk.

Any study is limited in scope, and this study is no exception. I examine only five defense-critical minerals cases during a relatively narrow 5-year window. Still, this work will add a systematic evaluation of what effects a variety of disruptive triggers can have on the U.S. supply
system. It will also identify how several causal relationships work in practice among the various factors identified by previous authors. Finally, I will discuss whether policy options currently under consideration are appropriate.

II. History Repeats Itself

While the threat of defense-critical mineral supply disruptions is not a new challenge, it was until recently a dormant one. Previous scholars produced the bulk and the best of the literature on this topic from the early 1980s through the mid-1990s and identified common factors involved with minerals supply chain vulnerability. It is worth setting the scene by explaining why market conditions of the 1980s and 90s proved so provocative for those concerned with national security at that time.

After experiencing several minerals and materials supply disruptions during World War II, the United States government established a series of commissions to examine the nature of the problem and determine what policy choices would help to ensure security of supplies. Through the 1970s, these commissions generally advocated purchasing whatever supplies were cheapest on the international market. The OPEC oil embargo and related oil crises of the 1970s brought this conclusion into question, as it became apparent that broader global conditions and political decisions by other countries could dramatically hinder the U.S. ability to purchase sufficient commodities supplies at affordable costs.
This sense of U.S. vulnerability to exogenous conditions drove a heightened concern over all nonrenewable commodities. Additional U.S. policy changes further contributed to their concerns. Environmental regulations enacted through the Nixon and Carter administrations raised concerns within domestic mining companies that their profits would suffer. In the 1980s, the Department of Defense also began selling off some minerals supplies from the strategic defense stockpile. Finally, supply disruptions and threats of disruptions by then-unstable South Africa, the hostile Soviet Union, and its satellites led to a wave of Congressional hearings, government reports, and independent analysis of the conditions contributing to U.S. vulnerability to supply disruptions. In world war-era parlance, policy makers and others concerned with minerals supplies categorized vulnerabilities as boiling down to “strikes and storms,” indicating concerns for labor strikes and disruptions by abrupt natural disasters. With the changing global security environment of the 1990s, however, scholars expanded the list of potential issues to include the following conditions:

- Lack of substitutes/uniqueness of specific minerals
- Lack of U.S. domestic supplies/dependence on foreign sources
- Geographic concentration of supplies
- Stability of producing countries and their regions
- Distances and routes of supply chains
- Availability of technology to recover and process the minerals

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• Economic price of the resources themselves
• Inability of foreign governments to coordinate minerals policies
• Level of domestic demand in producing country

Although many of these conditions of trade in minerals remain equally concerning today, attention to U.S. policies to reduce vulnerability to disruptions of defense-critical minerals waned as the Cold War ended. This deficiency is only recently being corrected, and focus is once again turning to minerals issues in reaction to two major supply disruptions – for rhenium and rare earths – in the past five years.

Since the last wave of serious debate and study of minerals issues, important changes have occurred in the defense industrial base and broader economy that further add to the importance of newly evaluating these conditions. These include China’s rising resource demand and the rise of warfare sculpted around computer and advanced communications equipment. It should prove valuable to build on the historical literature by comparing the findings of previous authors against contemporary cases.

Comparing the conditions identified as important in literature from past decades with modern circumstances will help illuminate policy options for addressing U.S. vulnerability to disruption. The time is ripe for a full review of potential warning signs of such vulnerabilities: policy makers today often take for granted that certain conditions are inherently problematic for the United States. For example, many policies in consideration today focus heavily on addressing import dependence broadly defined. However, the country has always been heavily reliant on foreign minerals supplies, often with no negative repercussions for U.S. supplies. The question is, what other conditions can combine with import dependence to make it particularly
problematic? In addressing this question, this work will examine a range of economic, geographic and political factors that can contribute to vulnerability.

III. Potential Points of Vulnerability

Though mineral supply chains differ for every mineral, several basic steps are common to most cases and are important to understanding potential points of vulnerability to disruptions. Once reserves are identified and evaluated as potentially profitable to exploit, companies must extract minerals. Especially given that most minerals are not pure ores – extracted resources will contain many different materials in various concentrations – the minerals must be processed and separated. Unless the deposits are processed on site, the minerals can be shipped multiple times before they form a source ready for use. Many minerals are sold in commodities markets, thereby involving additional intermediate steps. Finally, the minerals are purchased, shipped to their consumer, and used.

Given the nature of these supply chains, potential points of vulnerability for any given mineral may be grouped as economic, geographic, and political. I will therefore use these three categories to examine conditions for the minerals included in this study.

A) Economic Factors

Economic factors affecting resource vulnerability include demand and supply conditions. These conditions can be further categorized as: the nature of U.S. demand; the potential for substitution; the ability to economically recover and recycle minerals; import dependence;
concentration of suppliers; and whether supply is adequate to meet global demand in the long term.

First, with respect to demand, any discussion must begin with an acknowledgement that, to some extent, the United States creates its own vulnerabilities. For example, the U.S. government decides whether specific minerals will be critical to the production and use of defense equipment when it makes its acquisition decisions. Other states also follow suit, leading to rising or falling global demand. According to a 2008 National Academies of Science report, increasing global demand and reduced domestic minerals production threaten assured supplies of critical minerals, as does “higher risk of and uncertainty about supply disruptions owing to the fragmentation of global supply chains.” Changes in the level of domestic demand in mineral-producing countries can also affect export levels if supplies do not increase commensurately. However, clear information on domestic demand in foreign countries can be elusive for those conducting short-term academic research. Many countries do not thoroughly collect this information or make it public, and translation and cost barriers can also serve as a roadblock.

Of course the overlap between military needs and those of the private sector can also make tracking shifts in demand and their implications difficult. For example, classifying whether specific minerals meet the standard of “defense-critical” is less clear-cut than it once was given the modern military’s dependence on technologies with both defense and civilian uses, such as communications equipment, computers, and satellites. In any case, the effect is to make defense-

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9 Information on global demand by country can be available through expensive trade and investment reports that can cost thousands of dollars per document. However, one can imagine that issues of translation, false and inadequate information – and the proprietary nature of much relevant information – affect the accuracy of the data in these publications as well.
related supply of critical minerals vulnerable to the rise and fall of commercial use. All minerals examined in this study fall into this dual-use category. For example, niobium is mostly used in steel production and aerospace applications, rare earths in lasers and radar, and rhenium in turbine engine components and in superalloys because of its heat resistance.10

Table 1. Examples of Military and Civilian Uses of Select Minerals.11

<table>
<thead>
<tr>
<th></th>
<th>Rare Earths</th>
<th>Gallium</th>
<th>Rhenium</th>
<th>Niobium</th>
<th>Tantalum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common Uses</strong></td>
<td>• automotive catalytic converters</td>
<td>• integrated circuits</td>
<td>• petroleum-reforming catalysts</td>
<td>• steel production</td>
<td>• tantalum capacitors used in automotive electronics</td>
</tr>
<tr>
<td></td>
<td>• petroleum refining catalysts</td>
<td>• light-emitting diodes (LEDs)</td>
<td>• superalloys used in high-temp. turbine engine components</td>
<td>• niobium alloys and metal by the aerospace industry</td>
<td>• pagers</td>
</tr>
<tr>
<td></td>
<td>• metallurgical additives and alloys</td>
<td>• laser diodes</td>
<td>• semiconductors</td>
<td></td>
<td>• personal computers</td>
</tr>
<tr>
<td></td>
<td>• glass polishing and ceramics</td>
<td>• solar cells</td>
<td></td>
<td></td>
<td>• portable phones</td>
</tr>
<tr>
<td></td>
<td>• computer monitors</td>
<td>• opto-electronic devices (esp. in aerospace)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• radar</td>
<td>• telecommunications equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• permanent magnets</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>• lasers</td>
<td></td>
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</tbody>
</table>

Second, with respect to issues of supply, an important factor is whether a given mineral has unique properties that make substitution difficult or impossible. Rare earth minerals fall into this category. Niobium and tantalum can be replaced in some applications, but with loss of effectiveness. For rhenium, however, there are a variety of substitutes in use today, with


11 U.S. Geological Survey (2010). Note that most applications are for both military-specific and civilian equipment.
additional substitutes under regular testing and development. Gallium can be replaced for many of its uses, although some substitutes are vulnerable to disruptions and price spikes as well.\textsuperscript{12}

Third, the ability to economically recover and recycle minerals can indirectly create sources of supply. Minerals can be removed from manufactured items that are headed for the landfill, extracted, and recycled. Gallium, for example, can be recovered and reprocessed in some cases, as can rhenium, niobium, and tantalum. However, for most rare earths, very little material can be economically recycled or recovered today.\textsuperscript{13}

The fourth factor is perhaps the most-frequently identified economic factor that indicates U.S. vulnerability – a lack of domestic supplies and resulting dependence on foreign sources. This, however, is somewhat misleading. Many minerals are not (or no longer) produced in the United States for environmental reasons or because it is less economical than in other countries – not necessarily because American deposits of the minerals cannot be found. As global demand growth generates higher prices, the costs of extraction may become tolerable, making domestic supplies economical. For example, although the United States has been 100\% dependent on imports of rare earth minerals for years, this was not always the case: under various owners, rare earth reserves in California were once extracted. The United States also relies on imports to meet 100\% of its gallium consumption. Nor has the United States produced niobium or tantalum since prior to 1960.\textsuperscript{14} From 2005 to 2009, import dependence for rhenium hovered between 78 and 85\%.\textsuperscript{15}

Fifth, examining concentration of suppliers from the American perspective – as distinct from absolute import dependence and geographic concentration of reserves – adds deeper detail to examining vulnerabilities to disruptions. Various economic conditions can lead to concentration of suppliers, for example when low labor costs in one country price other potential producers out of the market. The United States has relied on China for an average of 91% of its rare earth supplies since 2005. The country also relies on a single country for more than two-thirds of its supplies of niobium (85% from Brazil) and rhenium (93% from Chile). In contrast, the United States imports tantalum from a far more dispersed network of suppliers, as it imports only 18% of supplies from its top supplier, Australia, and receives tantalum from more than a half dozen additional countries. Likewise, the top single U.S. supplier of gallium, Germany, supplies only about 24% of U.S. demand.16

Finally, perhaps a more useful (and accessible) measure is to examine whether world supply is adequate to meet global demand over the long term – information that the U.S. Geological Survey (USGS) provides. According to USGS calculations, the world’s supplies are adequate to meet long-term demand for each of the minerals examined here for decades in absolute terms. Economic conditions (namely the high costs of production versus prices) seem most likely to affect short-term supplies to market of gallium, rare earth minerals, and rhenium.17 In other words, the minerals supplies are there, but when and to what extent companies mine them is the more important question.

Indeed, decisions of whether or not companies or countries produce these minerals involve factors beyond just price. Several scholars have identified the availability of technology to recover and process specific minerals – which is often a function of the economic ability to invest in technology – as an important factor in considering vulnerability to disruptions. Technological capability is certainly a factor in China’s production of rare earth minerals, given the extensive processing needed to economically produce them. For the purpose of the comparison in this study, I consider that this factor generally manifests in the concentration of suppliers that actively produce the minerals I examine.

Some scholars list of prices of minerals themselves as a factor to watch in monitoring vulnerability to disruptions. The rise and fall of prices, however, result from a wide range of factors, and the correlations between prices and vulnerability are complex, as the discussion of the economics of extraction suggests above. For the purpose of this study, I therefore consider prices to be either a signal of declining vulnerability (over the long term) or a potential result of supply disruptions (over the short term) – not a signal that disruptions may occur.

B) Geographic Factors

Another set of factors relate to the geographic location of minerals, which include concentration of supplies and abrupt events that can disrupt supplies – namely natural disasters and severe storms.

First, scholars have consistently identified geographic concentration of supplies as a critical factor in determining vulnerability to disruptions. Kent Hughes Butts, for example, wrote in 1993, “Because of the physical concentration of strategic mineral reserves, the collapse of one
of the major mineral producing states could result in significant shortfalls that would have a devastating impact on the U.S. economy and the ability of the United States to reach its objectives in a surge capacity.”\textsuperscript{18} It is worth examining this assertion in detail.

Despite rare earth minerals serving as the currently most severe case of disruptions carrying security and foreign policy implications, this class of minerals is not particularly geographically concentrated. At least eight countries have known reserves, and to-date unfound reserves are expected to be high. The media often refers to China as having a corner on rare earths because it produces and exports almost all of current world supplies. However, it possesses only about 36% of known world reserves – not a terribly high concentration.\textsuperscript{19} One may therefore presume that the loss of a single major supplier such as China may increase the costs of supply, but not necessarily their long-term availability.

Other defense-critical minerals appear to be more geographically concentrated than rare earth minerals are. Chile holds about 52% of world reserves of rhenium, followed by the United States (with about 15% of reserves) and many other smaller-scale producing countries. Known tantalum reserves are even more concentrated, mostly in Australia and Brazil, and Brazil also possesses between 80% and 90% of the world’s niobium deposits.\textsuperscript{20} Gallium presents a difficult case to compare, as it is found only in other mineral ores – deposits never exist alone in nature. According to the USGS, “Only part of the gallium present in bauxite and zinc ores is recoverable, and the factors controlling the recovery are proprietary. Therefore, an estimate of

\textsuperscript{18} Butts, xi.
current reserves comparable to the definition of reserves of other minerals cannot be made.”

However, neither bauxite nor zinc (the two minerals with which gallium is most often found) are highly geographically concentrated.

The geographic locations of mineral reserves are mostly static (though human identification of those locations changes with time). In a second category, many scholars therefore point to abrupt events – namely natural disasters and severe storms – as important in predicting likelihood of disruptions. The locations and severity of storms of course vary with time, but for the purpose of this study, natural disasters were not the causes of the two major disruptions examined in this study (rare earth minerals and rhenium). It is worth noting, however, that storms in the United States can likewise halt shipments into the country.

Shipping minerals from their point of extraction to their customer could also be a vulnerable link in minerals supply chains. It seems to make logical sense that vulnerability could directly correlate with distance: the further minerals must travel to their end user, the greater the risk that something will go wrong. The globalization of supply chains discussed above, however, has given a unique character to modern supply chains that has made the length of routes increasingly irrelevant. In some cases, air transit is more economical than maritime freight, which could reduce opportunities for disruptions despite long distances between exporter and importer. Likewise, supplies traveling through unstable or inefficient Latin American countries, or through the most violence-plagued Mexican cities, could potentially be vulnerable to disruption despite their relatively short journey to the United States.

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C) Political Factors

Minerals supply disruptions can result from political or policy decisions, either by the United States or others. Authors in the past have often pointed to domestic regulations (particularly environmental regulations) as restricting minerals production. Many political factors, however, are difficult to measure. Beyond regulations, important political factors include instability of producing countries and their regions, strikes, and lack of U.S. government stockpiles.

First, political stability of producing countries and their regions has, not surprisingly, remained a major concern through the past century. Comparing producing countries of the minerals I examine here against the Failed States Index, an annual report on state stability produced by Foreign Policy magazine and the Fund for Peace, provides an indication of the strength of this factor for this set of minerals. Today’s primary producer of rare earth minerals, China, ranks as the 57th-least stable country in the world, though it is not classified as being within the “alert” zone in the index. Potential rare earths producing countries, including the United States, Australia, Brazil and Malaysia, are among the world’s most stable 50% of countries. Rhenium-producing countries tend to be moderately or primarily stable, including the United States, Canada and Chile, with Russia and Kazakhstan among the less stable rhenium exporters. For gallium, all but two important producers (China and Russia) are among the most

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23 Analyzing the effects of a broad range of regulations is beyond the scope of this study, which examines supply disruptions rather than prices or long-term incentives and disincentives.
stable half of countries. The major producers of niobium (Brazil and Canada) and tantalum (Australia and Brazil) are generally stable.24

This stability index evaluates political conditions only at the aggregate state level. In a second category, political disruptions can occur at the local level as well, most notably in the form of labor strikes. The 2010 USGS minerals commodity summaries and other U.S. government assessments highlight three cases of strikes disrupting minerals supplies over the past five years (bismuth, cobalt, and nickel), but does not indicate that strikes affected any of the cases I examine in this study.25

Finally, at the national level, political considerations – including misperceptions -- can drive leaders to increase the stockpiles of minerals critical to defense needs. Overconfidence in or lack of attention to minerals markets can have the opposite effect. In the United States, for example, Congress has instructed the Department of Defense to sell off minerals from the National Defense Stockpile Center since the early 1990s. While the U.S. government does appear to stockpile tantalum and niobium, it does not currently stockpile rhenium, gallium, or rare earth minerals.26 Perhaps even more important, current stockpiling policies are relics of the World War II era and do not adequately reflect modern supply chain management.

Causes of political conditions that can influence mineral supply availability include both international geopolitical calculations and domestic factors. In some cases, producers (whether

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25 One minor strike of at least 10 days did stop tantalum production in Mozambique in 2008; and American industries did experience a shortage of tantalum capacitors in 2000 and 2001. However, these circumstances do not appear to have triggered notable disruptions in supplies to the United States. “Mozambique: Miners in Zambezia on Strike,” Africa News (21 February 2008); and Doug Bartholomew, “Supply Chains at Risk,” Industry Week (October 2006).
companies or countries) deliberately withhold supplies. Their decisions to do so depend, in part, on their calculation of the economic impact and their ability to control the global market. But sometimes the decisions are simply political and even rash. China’s triggering of rare earth minerals supply disruptions certainly highlights this point. In 2007, the U.S. State Department was forced to intervene when China halted shipments of rare earths to a U.S. petroleum refining and chemicals company for so long that it drove concerns for nationwide refined petroleum shortages.\textsuperscript{27} In 2010, a second disruption hit Japan after a dispute with China over a skirmish in the East China Sea. As the Japanese detained the captain of the Chinese boat involved in the incident, Japanese companies began reporting to their government that shipments of rare earths from China were being suspended. Chinese officials denied that it had instituted an official embargo, but Japanese firms continued to report supply disruptions for several weeks.\textsuperscript{28} These types of bold geopolitical moves can generate sticky foreign policy problems in addition to the direct effects of supply disruptions.

Political disruption can also reflect internal crises. Rhenium serves as the other mineral for which the United States experienced a supply disruption within the scope of this study, and in this case the trigger was a domestic political issue – albeit one with economic dimensions. According to the USGS, exports from Kazakhstan, which supplied 25% of U.S. demand, “were halted from the third quarter of 2005 until the fourth quarter of 2006.” A supplier to Kazakhstan’s state-owned rhenium producer blocked trade over a financial dispute amid

\textsuperscript{28} See, for example, “China Halts Top-Level Ties with Japan over Dispute,” \textit{BBC News} (19 September 2010); Risa Maeda and Chikako Mogi, “Japan Trade Min. Hears China Rare Earth Exports Halted,” \textit{Reuters UK} (24 September 2010); and Jae Hur and Emi Urabe, “Ohata Urges China to Export More Rare Earths as 124 Firms Face Shortages,” \textit{Bloomberg News} (5 October 2010).
additional political tensions between governing officials who variously wanted to open rhenium reserves for foreign investment and, on the other side, expand the state’s monopoly. By early 2006 rhenium prices were rising precipitously, just as demand was increasing for use in petroleum refining and, in particular, in jet engine production.

This discussion raises the question of whether there is clear evidence that any of these factors are more or less important in signaling U.S. vulnerabilities to supply disruptions.

IV. Comparing the Conditions

Comparing these factors across several minerals – including ones for which the United States did and did not experience a supply disruption – may assist in learning whether any factors strongly indicate vulnerability. This may also illuminate whether certain factors seem to combine in ways that increase the likelihood of disruptions.

Table 2 below shows the array of factors that can contribute to U.S. vulnerability to mineral supply disruptions. It also shows the complexity of this challenge. It appears that no single causal factor alone can serve as an effective warning sign that the United States may experience disruptions for all minerals. Gallium and rare earths exhibit the same geographic factors; as do rhenium, niobium, and tantalum. Rare earths and niobium share the same profile in terms of the economic factors examined here, as do gallium and tantalum. Certainly sufficient world supplies to meet demand, for decades into the future, does not make a strong impression in

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indicating potential short-term vulnerability. The only two minerals for which the United States experienced disruptions in the time period I examine, rhenium and rare earths, differ in whether reserves are geographically concentrated and in most economic factors. This indicates a need for policy makers to examine a wide range of factors specific to each defense-critical mineral in order to best hedge against disruptions.
Table 2: Comparison of key vulnerabilities for five minerals.

<table>
<thead>
<tr>
<th>Types of Vulnerabilities</th>
<th>Rare Earths</th>
<th>Niobium</th>
<th>Tantalum</th>
<th>Rhenium</th>
<th>Gallium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of substitutes/uniqueness of specific minerals (esp. in defense applications)</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Importance of specific minerals for producing defense equipment</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Inability to recover and recycle economically</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Import dependence for &gt;90% of supplies</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Known supplies inadequate to meet projected global demand</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Concentration of suppliers (fewer than 3 suppliers for &gt; 2/3 of supplies)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes/No</td>
<td>No</td>
</tr>
<tr>
<td>Geographic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geographic concentration of supplies (&gt;50% known reserves in single country’s possession)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Major natural disasters (that created major disruption to United States)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Political</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instability of producing countries and their regions</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Strikes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Lack of U.S. government stockpile</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Key: Each “yes” indicates that between 2005 and the present, that mineral exhibited the vulnerability listed; each “no” indicates the opposite. The more “yeses” each mineral has listed, therefore, the more policy makers should be concerned for its vulnerabilities. The minerals with the greatest number of vulnerabilities are to the left, and the least number of vulnerabilities to the right of the table. As you can see, rare earth minerals – of which the United States most recently experienced supply disruptions – exhibit the greatest number of vulnerabilities. (Sources as listed in the bibliography and footnotes; table compiled and created by the author.)

31 It remains difficult to quantify concentration of suppliers, which is a regularly moving target. Mines go in and out of production regularly, and often countries cease producing their potential supplies for economic or environmental reasons. For this study, isolating a relatively short, five-year time period along the lines of recent USGS assessments aided in identifying concentration of suppliers.
In order to examine more closely the utility of considering these factors, it is worth examining these conditions for the two disruptions specified in this report: rare earth minerals in 2007 and rhenium from 2005 to 2006.

In 2007, at the time of the disruption of rare earth mineral shipments to the United States, the country was 100% reliant on imports. China, at that time classified by the Failed States Index as in the “warning” category as the 68th-least stable country in the world, provided 84% of these supplies. France, Japan, Russia and a few other countries provided the additional supplies to the United States. As is the case today, in 2007 the United States neither stockpiled rare earths nor had good substitutes for them in defense applications, and it was not economical to recycle these minerals. Indeed, as Table 3 shows, rare earths exhibited an array of vulnerabilities in 2007.

Table 3: Comparison of Vulnerabilities for Rare Earths in 2007.

<table>
<thead>
<tr>
<th>Lack of substitutes</th>
<th>Importance in producing defense equipment</th>
<th>Inability to recover &amp; recycle economically</th>
<th>Import dependence for &gt;90% of supplies</th>
<th>Known supplies inadequate to meet demand</th>
<th>Concentration of suppliers</th>
<th>Geographic concentration of supplies</th>
<th>Major natural disasters</th>
<th>Instability of producing countries</th>
<th>Strikes</th>
<th>Lack of U.S. government stockpile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

These conditions differed starkly for rhenium between 2005 and 2006, when a cutoff of supplies to the United States set prices climbing from $1,170 per kilogram in 2005 to over $5,000 per kilogram by mid-2006. In 2005, the United States relied on imports for 80% of its rhenium supplies, and this dependence grew to 87% in 2006. During these years, concentration of suppliers was high, with Chile, Kazakhstan and Germany providing 77% of imports. While Chile and Germany were considered at that time to be moderately stable countries, the Failed
States Index classified Kazakhstan in its “warning” category in both 2005 and 2006 – not severely unstable but concerning. It appears that the only major vulnerabilities for rhenium at the time of the major disruption of supplies to the United States were its concentration of suppliers and lack of government stockpiles.32

Table 4: Comparison of Vulnerabilities for Rhenium from 2005 to 2006.

<table>
<thead>
<tr>
<th>Lack of substitutes</th>
<th>Importance in producing defense equipment</th>
<th>Inability to recover &amp; recycle economy</th>
<th>Import dependence for &gt;90% of supplies</th>
<th>Known supplies inadequate to meet projected demand</th>
<th>Concentration of suppliers</th>
<th>Geographic concentration of supplies</th>
<th>Major natural disasters</th>
<th>Instability of producing countries</th>
<th>Strikes</th>
<th>Lack of U.S. government stockpile</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Political leaders and media commentators frequently point to import dependence as a major factor in determining vulnerability to disruptions. Rhenium is notable, then, as the mineral in this study for which the United States is the least dependent on imports in this comparison – and as one of the two cases for which the country experienced a major supply disruption. This seems to indicate that a high degree of import dependence is not in itself cause for concern, but rather the nature of that dependence can be concerning. In this case, concentration of suppliers appears to have played one of the most important roles in indicating vulnerability.33

Rhenium continues to be interesting in this regard. The United States today meets about 21% of its own rhenium demands. For its imports, suppliers are even more concentrated today

than in 2005/06, with Chile supplying 93% of rhenium metal powder imports and Kazakhstan supplying 68% of ammonium perrhenate.34

While the economic condition of supplier concentration appears to play an important role, it is worth recalling that political factors had a major hand in both of the disruption cases examined here. Both the rhenium and rare earths disruptions involved decisions to cut off minerals supplies that were partially political in nature. The cases examined here, however, appear to differ from the political concerns of previous decades, where supply disruption concerns focused heavily on political instability in exporting countries and labor strikes; in other words, disruptions tended to occur in the absence of strong political leadership. Both the rhenium and rare earth minerals disruptions of the past five years were triggered by overt decisions made by political leaders. These decisions involved leveraging positions of strength, not chaos or disorder.

V. Is Current U.S. Policy Appropriate?

Over the past year, the media and the federal government have highlighted several specific cases of minerals-related problems for the U.S. security community, with the current China/rare earths case the most frequently discussed.35 Concern for this issue is rising. American vulnerabilities to supply disruptions could lead to persistent cost overruns, lags in equipment delivery, and leverage provided to sometimes-hostile supplier countries. In addressing this risk, it is tempting to leap to what may seem the most compelling indicator – often import dependence – in prescribing solutions to reduce U.S. vulnerability. Given the recent attention by high-level

Obama administration officials, Congress, and the media, and the need for deeper consideration of what indicates vulnerability, this research examined what factors contribute to increased U.S. vulnerability to mineral supply disruptions. Without more systematic evaluations of the factors involved with minerals supply issues, new policies may be informed more by conjecture and unproven assumptions about this area of trade than by hard analysis of these vulnerabilities.

This study indicates three important guidelines for policy makers to respect in addressing U.S. vulnerability to minerals supply disruptions.

First, respect the complexity of the challenge. No policy prescription aimed at a single geographic, economic, or political variable will suffice in reducing U.S. vulnerability to supply disruptions. This is a problem that requires thorough research. It calls for analysts digging into details across a range of economic, geographic, and political factors – while considering how minerals are used in defense applications. There is likely no clear, universal combination of traits that make specific defense-critical minerals more or less vulnerable to supply disruptions. Congressional staffs and executive branch officials must ensure that they have the requisite time and personnel dedicated to understanding the complexity of this issue if they are going to develop sound policies to reduce the likelihood or impact of disruptions.

Second, policy makers must switch attention from the location of physical reserves of critical minerals to concentration of suppliers. The key will be to designate officials within the government to track changes in concentration of suppliers as a warning sign of vulnerability to disruptions – or to find nongovernmental entities that can readily and consistently provide this tracking.
Finally, policy makers must drop the current distraction with undifferentiated assessments of import dependence and focus on variable and relative dependency instead. While supporting domestic production may be a useful remedial action in reducing vulnerability to disruptions, labeling the problem as that of simple import dependence buries the complicated sets of factors that indicate true risk. Increased domestic production is not possible for all minerals. Furthermore, increasing domestic sourcing would likely remain insufficient for entirely curbing dependence on imports. Given that some degree of import dependence for minerals is an unavoidable reality, policies that look beyond bolstering domestic production will be necessary.

Long-practiced policies such as promoting substitution and stockpiling can be effective in reducing U.S. vulnerabilities to supply disruptions. Policy makers, however, must also provide a sense of prioritization. Given that this is a global issue and involves more than 100 distinct minerals, seeking to address all cases and contingencies would likely have negative side effects or be so broad as to lack effectiveness. Tracing the factors identified in this study as most important can form the basis for a strategy to avoid or mitigate the worst-possible disruptions.

Policy makers can maximize the potential of substitution by relying on rigorous identification of minerals for which decreasing demand is most important, and offer incentives or mandating investment in developing substitutes for these minerals. For example, aircraft manufacturers are actively trying to reduce the amount of rhenium used in alloys and develop substitutes for it where possible, but this of course followed the experiences of supply disruptions and rising prices.\textsuperscript{36} Stockpiling minerals that meet several criteria (for example,

importance to defense production, lack of diversity of suppliers, and high global demand growth) is also likely to continue to be one of the best policies for ensuring supplies of needed materials.

Whatever policies decision makers consider, they will be most effective if they are based on a rigorous study of the different factors that can generate problems in the minerals trade for the United States.

VI. Conclusion

This initial study suggests the importance of creating a suite of policy prescriptions that address a range of potential vulnerabilities. The next logical step in building on this work would be to continue this type of evaluation for additional minerals to see if these results remain consistent. In particular, it would be useful for future researchers to expand on this work by examining minerals exported from the Democratic Republic of Congo (DRC), which is the primary world supplier of several critical minerals and has uniquely unstable political and economic conditions. The DRC has large reserves of coltan, a mineral critical in cell phones and other electronics that is intimately intertwined with the domestic conflict in that country. Though accurate information is not forthcoming, exploring the unique conditions surrounding its supply chains could be instructive. Lithium would likewise be useful for comparison. While its demand is not particular to defense applications, its consumption is rising swiftly for its use in hybrid vehicles. The media has also trained attention to this mineral through 2010 because of the large
reserves held by Bolivia, whose leadership is not always warm to U.S. businesses and system of capitalism.\textsuperscript{37}

I began this analysis with a goal of looking “beyond storms and strikes” for what factors are most important in indicating U.S. vulnerability to supply disruptions of defense-critical minerals. Through the course of this research, I realized that storms and strikes no longer scrape the surface in describing the range of potential vulnerabilities. Indeed, the differences between the disruption cases of rare earth minerals and rhenium examined in this study – and the range of conditions seen with the other three minerals – show the need for scholars to continue expanding and testing the list of conditions that can indicate vulnerability to disruptions. As the world’s population rises and developing countries build their economies, the resulting increase in global demand for minerals will prove that this complicated challenge is worthy of far more extensive research.

\textsuperscript{37} U.S. Geological Survey, (2010): pp. 92-93. In addition, the aforementioned 2008 National Academies of Science assessment also identifies several factors important in supply disruptions that I did not contrast in this study’s cases because they have not been explicitly addressed by the historical literature that I examined. These include a conventional or unconventional “military attack on the U.S. homeland,” military conflict abroad, including in the maritime domain, and “epidemic diseases in foreign countries.” A comprehensive comparison of warning signs for supply disruptions in the modern defense industrial base would include examining how (and if) these factors do indeed contribute to serious disruptions.
Bibliography


