AGU GIFT Workshop 2015: Human Dependence on Earth's Mineral Resources Activities

Making learning visible: Concept mapping a resource

Sign up for one of the following commodities:

graphite	platinum-group metals	gypsum
tantalum	bauxite	manganese
tungsten	silica	lithium
gold	tin	REEs
chromite	iron	sulfur
copper	clays	phosphate
halite	cobalt	industrial diamonds
molybdenum	lead	zinc
nickel	cadmium	

Note: Some of the **commodities** in the list above are **mineral resources** (rocks and minerals), whereas others are elements extracted from mineral resources.

Use what you have learned about mineral resources as well as information about your specific commodity to draw a concept map showing:

- The geologic nature of the resource: for example, what is the mineral resource and the resultant commodity (mineral, rock, or element); what mineral and rock forming processes acted to create the commodity; in what geologic/geographic settings might these processes have occurred?
- Physical characteristics of the resource.
- The factors and people (people could be countries, companies, etc.) who determine the demand for the resource: for example, what is the commodity used for, who uses it, and what other things might influence the demand for this resource?
- The methods of mining and processing the commodity: for example, how and where does mining and processing occur; what environmental impacts occur; who is impacted by the overall mineral recovery process and in what ways?

Ideally, you should start this as soon as possible, filling in as much as you already know. Throughout this module, **add to your concept map** as you learn more about the commodity you choose and about mineral resources in general. You will use materials that you are learning in class, but you will also need to do *extra research and work outside of the class.*

Resources that may be helpful in addition to class may include your textbook, the USGS Minerals Yearbook website (http://minerals.usgs.gov/minerals/pubs/myb.html), the Mineral Information Institute website (http://www.mii.org/welcome), as well as other webpages. When you turn in the assignment, please include a list of the sources (with web addresses as appropriate) that you used to complete your concept map, although you do not have to denote which information you obtained from each source.

links to interesting videos:
tantalum - https://www.youtube.com/watch?v=euISyPnK0ag
tungsten - https://www.youtube.com/watch?v=E2haKbrLbOQ
tin - https://www.youtube.com/watch?v=u6KxzGMF4co
gold - https://www.youtube.com/watch?v=1RavnNnv5ns
gypsum
halite
copper
bauxite

cobalt
iron
cadmium
chromite
lead
lithium
nickel
platinum (Platinum group metals)
REEs
silica
sulfur
zinc
clay
phosphate
diamonds (industrial, not gemstones)

Rubric for Concept Map

	Exemplary 4	Exceeds standard 3	Meets standard 2	Below standard 1	Score
Organization	• Well organized • Logical format • Map is "treelike" and not stringy • Follows standard map conventions	• Thoughtfully organized • Easy to follow most of the time • Follows the standard map conventions	• Somewhat organized • Somewhat incoherent	• Choppy and confusing	
Geologic nature of the resource					
Content	• All of the main concepts from the module are covered	• Almost all of the main concepts from the module are included	• The majority (>50%) of concepts from the module are included	• Many of the main concepts from the module are missing	
Connections	• The map answers the key questions asked in the instructions • Uses appropriate terminology (terms used in class) • All nodes (concepts) are accurately connected • Links are precisely labeled • Linking words demonstrate conceptual understanding • No misconceptions/errors evident	• The map answers most of the key questions asked in the instructions • Uses appropriate terminology (terms used in class) • All nodes (concepts) are accurately connected • Connections are clear and logical. They connect concepts to promote clarity and convey meaning. • Linking words are easy to follow but at times ideas unclear or connections incorrectly labeled • May contain some small errors	• The map answers some of the key questions asked • Most words are accurately connected • Connections are somewhat clear and convey some meaning • Makes some incorrect connections • Some links are not labeled • May contain errors	• The map answers some of the key questions asked • Only some concepts are accurately connected • Labels aren't clear, they convey little meaning and do not promote clarity • Many links are not labeled • May contain many errors, and/or concepts that don't belong	
Factors and people who determine resource demand					
Content	• All of the main concepts from the module are covered	• Almost all of the main concepts from the module are included	• The majority (>50%) of concepts from the module are included	• Many of the main concepts from the module are missing	
Content and connections	• The map answers the key questions asked in the instructions • Uses appropriate terminology (terms used in class) • All nodes (concepts) are accurately connected • Links are precisely labeled • Linking words demonstrate conceptual understanding • No misconceptions/errors evident	• The map answers most of the key questions asked in the instructions • Uses appropriate terminology (terms used in class) • All nodes (concepts) are accurately connected • Connections are clear and logical. They connect concepts to promote clarity and convey meaning. • Linking words are easy to follow but at times ideas unclear or connections incorrectly labeled • May contain some small errors	• The map answers some of the key questions asked • Most words are accurately connected • Connections are somewhat clear and convey some meaning • Makes some incorrect connections • Some links are not labeled • May contain errors	• The map answers some of the key questions asked • Only some concepts are accurately connected • Labels aren't clear, they convey little meaning and do not promote clarity • Many links are not labeled • May contain many errors, and/or concepts that don't belong	

Continued on the next page

	Exemplary 4	Exceeds standard 3	Meets standard 2	Below standard 1	Score
Resource mining and processing					
Content	• All of the main concepts from the module are covered	• Almost all of the main concepts from the module are included	• The majority (>50%) of concepts from the module are included	• Many of the main concepts from the module are missing	
Connections	• The map answers the key questions asked in the instructions • Uses appropriate terminology (terms used in class) • All nodes (concepts) are accurately connected • Links are precisely labeled • Linking words demonstrate conceptual understanding • No misconceptions/errors evident	• The map answers most of the key questions asked in the instructions • Uses appropriate terminology (terms used in class) • All nodes (concepts) are accurately connected • Connections are clear and logical. They connect concepts to promote clarity and convey meaning. • Linking words are easy to follow but at times ideas unclear or connections incorrectly labeled • May contain some small errors	• The map answers some of the key questions asked • Most words are accurately connected • Connections are somewhat clear and convey some meaning • Makes some incorrect connections • Some links are not labeled • May contain errors	• The map answers some of the key questions asked • Only some concepts are accurately connected • Labels aren't clear, they convey little meaning and do not promote clarity • Many links are not labeled • May contain many errors, and/or concepts that don't belong	
Includes references (1)					
Legible with (mostly) correct spelling (1)					
Total (out of 30)					

Human's Dependence on Earth's Mineral Resources
Unit I
People, Products, and Minerals
Post-class homework

Learning objectives

- Infer the relationships between sustainability, resource availability, population growth, and economic development.
- Extrapolate the impacts of growing populations and economic development on mineral resource extraction and use.

Population, economic development, and mineral resource use

In 1900, an estimated 1.65 billion people lived on Earth. Today, the population is more than 7 billion and still growing. By 2100, it is believed that an estimated 8–11 billion people will inhabit the Earth.

Every organism needs resources to provide food, water, shelter, and a location for waste disposal/processing. These resources are provided by the environment, which may include other organisms. Humans are unique in that we utilize so much of the planet for resource extraction and waste disposal to meet our needs and our desires. Our ability to innovate and act has enabled many of us in the developed world to enjoy a high standard of living, reshaping resources into "stuff" and consuming beyond our basic needs. For example, in 2005, the United States used 15% of extracted mineral resources but is only home to 5% of the world's population (Gierlinger and Krausmann, 2011).

→ Watch the TED talk "Global Population Growth, Box by Box" given by Hans Rosling (approximately 10 minutes) at: http://www.ted.com/talks/hans_rosling_on_global_population_growth.html. There is an "Interactive Transcript" in the bottom right corner of the video if you want to read along. It might be helpful to read through the questions below before you watch the video.

1) Write down 10 items that you own that you feel you need in our modern U.S. society but that are in excess of truly basic survival needs (such as food, water, shelter, etc).

2) Circle any of the items on the list above (#1) that you think are likely to be owned by someone in an impoverished country.
3) In what ways might population growth affect mineral resource extraction and use? Explain your answer.

4) Rosling, in this TED talk, foresees an end to population growth. What factors does Rosling cite as reasons why population will stop growing? (These factors lead to an increase in child survival rate and a decrease in birth rate.)

5) In what ways might increased economic development (more impoverished countries becoming emerging economies, and more emerging economies becoming developed countries) affect mineral resource extraction and use? Explain your answer.

Citation: Gierlinger, S., and Krausmann, F. 2012. "The Physical Economy of the United States of America." *Journal of Industrial Ecology* 16: 365–77.

People, Products, and Minerals
Unit 1/Activity 3

Economic Development and Resource Use

Learning Outcomes

- Infer the relationships among sustainability, resource availability, population growth, and economic development

Economic Development and Resource Use

The gross domestic product (GDP) of a country is frequently used as an indicator of a country's economic performance and its level of development. A per capita GDP is the overall GDP divided by the number of people in that country and can be used to more easily compare the economic performance of countries with different population sizes.

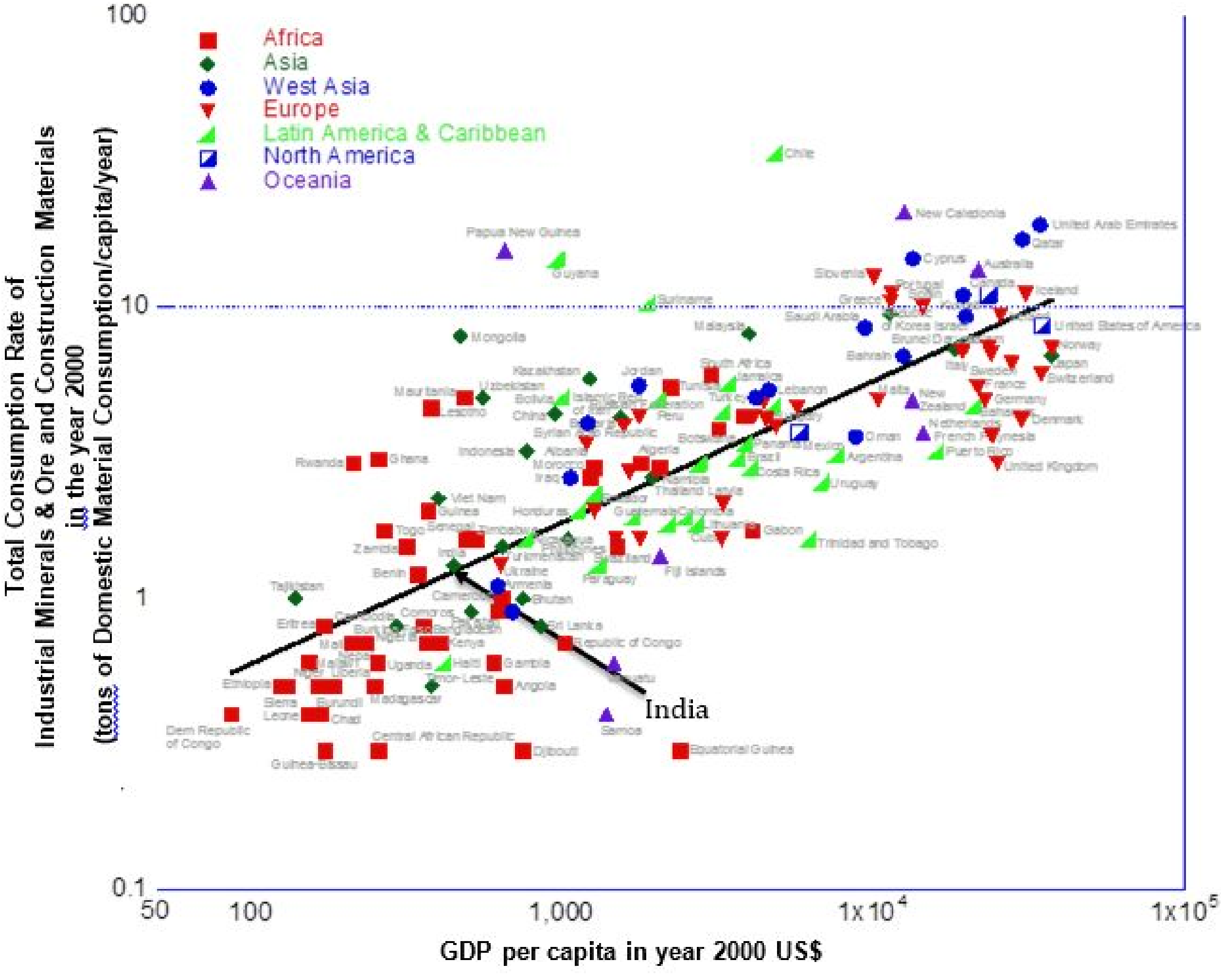


Figure 1. ***The relationship between gross domestic product (GDP) per capita and the total domestic consumption rate of industrial minerals & ore and construction material in tons per capita for ~150 different countries in the year 2000*** (Modified from UNEP Decoupling Report, 2011; Consumption (metabolic) rate data from Steinberger et al., 2010; GDP data from http://data.worldbank.org/indicator/ NY.GDP.PCAP.KD); Country region from http://unstats.un.org/unsd/methods/m49/m49regin.htm with the exception of considering Mexico as part of North America). Not all the countries plotted are labeled above due to space restrictions.

The plot above shows the per capita GDP of many countries versus a measure of their natural resource *consumption rate*. In this case, *consumption rate* is the domestic extraction of a material plus its imports minus its exports of those same materials (in tons per capita per year). In this case, the natural resources measured are Industrial Minerals & Ore and Construction Materials. As the legend denotes, different regions of the world are indicated by markers of different colors and shapes.

<u>Questions</u>

1) Provide the names of two countries that consume approximately the same amount of resources but have widely varying per capita GDP's.

2) Provide the names of two countries that have approximately the same per capita GDP but have widely varying total consumption rates.

3) Despite the pairs noted above, use the trend line in Figure 1 to describe the overall relationship between a country's wealth, as defined by its per capita GDP, and the amount of natural resources used (per capita), as defined by its total consumption rate.

4) Is India more or less developed (as determined by per capita GDP) than most of the Latin American and Caribbean countries (which includes South America)?

5) Using this trend (from #3) predict what will happen as India's economy grows.

Figure 2 (*below*) shows consumption and extraction trends for various types of products in three different regions (North America, South America, and India) since around 1970.

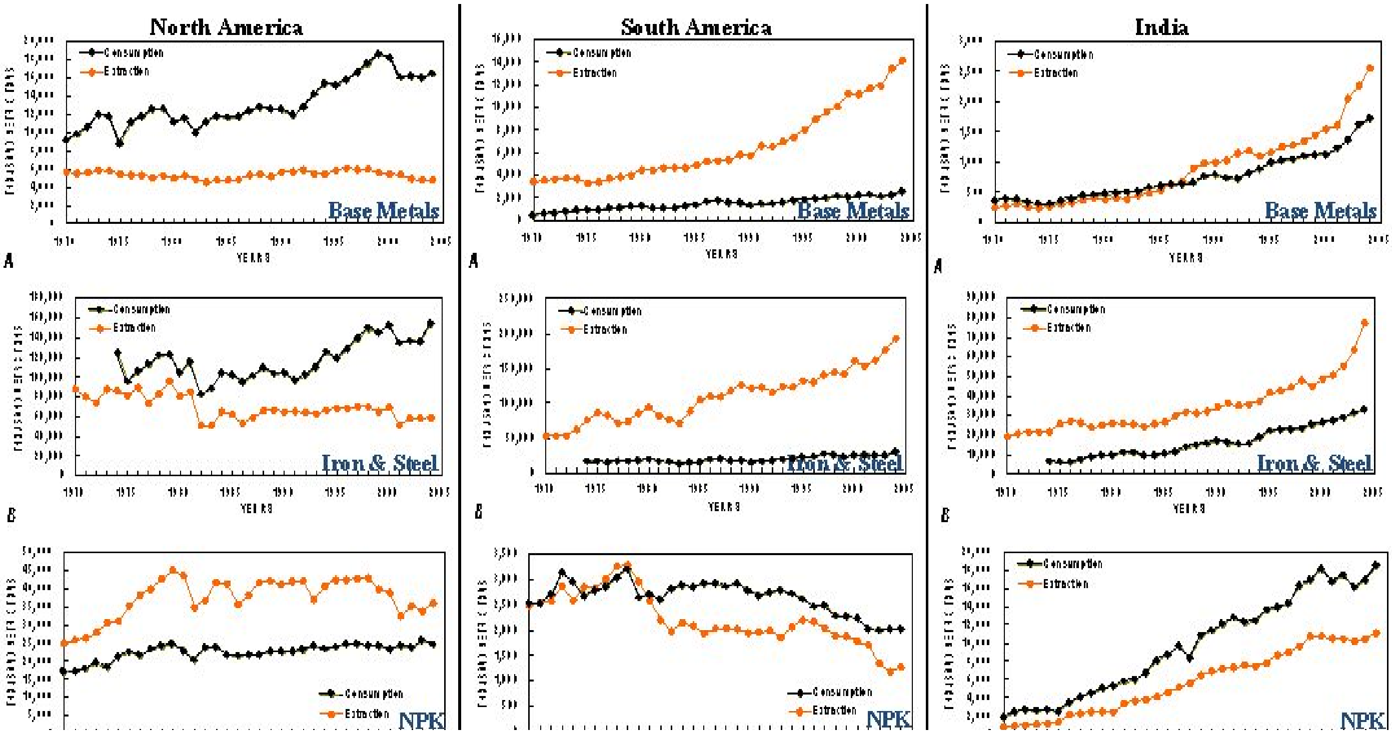


Figure 2: ***Consumption and extraction of various specific commodities in thousand metric tons for North America (left), South America (middle) and India (right).*** **A. Base metals (Aluminum, copper, lead, and zinc); B. Iron and steel; C. NPR (Nitrogen, phosphorus, and potassium), components often used in the production of fertilizer. From Rogich and Matos, 2008. North America includes the Canada, the United States, and Mexico.**

6) Describe the trends in consumption (toward more recent times) for all three regions.

7) Give a possible explanation for the trends in consumption in India. In North America?

8) India currently uses more NKP than South America, even though India is less developed. Why might that be the case?

Source Information for Figures:

Figure 1 Consumption (Metabolic) Rate data:

Steinberger, J., Krausmann, F., and Eisenmenger, N. (2010). "The Global Patterns of Materials Use: A Socioeconomic and Geophysical Analysis." *Ecological Economics* 69, no. 5: 1148–58. Data downloaded for plotting from: http://www.uni-klu.ac.at/socec/inhalt/3812.htm (see "Get data" link).

Figure 1 GDP per capita for constant 2000 US$ data for the year 2000:

Downloaded from http://data.worldbank.org/indicator/NY.GDP.PCAP.KD.

Figure 1 Country Classification:

From the United Nations Statistics Division at http://unstats.un.org/unsd/methods/m49/m49regin.htm. Exception is that Mexico is considered on the plot to be part of North America, rather than Latin America/Central America.

Figure 1 concept (and general source of information):

Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E. U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A., and Sewerin, S. (2011). *Decoupling Natural Resource Use and Environmental Impacts from Economic Growth.* A Report of the Working Group on Decoupling to the International Resource Panel. United Nations Environment Programme. Downloaded from http://www.unep.org/resourcepanel/decoupling/files/pdf/decoupling_report_english.pdf on November 15, 2012 (Figure 2.6 on page 14).

Figure 2: Data and concept

Rogich, D. G., and Matos, G. R. (2008). "The Global Flows of Metals and Minerals." U.S. Geological Survey Open-File Report 2008-1355. 11 pg., available only online at http://pubs.usgs.gov/of/2008/1355/.

Other Information:

Fridolin, K., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, H., and Rishcer-Kowalski, M. (2009). "Growth in Global Materials Use, GDP and Population During the 20th Century." *Ecological Economics,* 68, no. 10: 2696–705.

Gross Domestic Product. *Encyclopedia Britannica* http://www.briannica.com/EBchecked/topic/246647/gross-domestic-product-GDP) (accessed November 15, 2012).

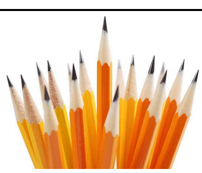
SERI, 2011. Global Resource Extraction by Material Category 1980–2008. . http://www.materialflows.net/trends/analyses-1980-2008/global-resource-extraction-by-material-category-1980-2008/ (accessed September 12, 2012).

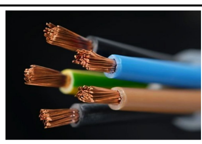
Humans' Dependence on Earth's Mineral Resources
People, Products, and Minerals
Part I: Minerals and Products

Here is a list of the minerals, and their chemical formulas, that we have in class today. Use this, and other properties of the minerals (such as hardness, color, etc.), to match them to the products listed on the back of this sheet (one mineral per product).

Mineral Name	**Chemical Formula**
Apatite	$Ca_5(PO_4)_3(F,Cl,OH)$
Bauxite	$Al(OH)_3$ - $AlO \cdot OH$
Barite	$BaSO_4$
Calcite	$CaCO_3$
Chalcopyrite	$CuFeS_2$
Galena	PbS
Graphite	C
Gypsum	$CaSO_4 \cdot 2(H_2O)$
Halite	NaCl
Hematite (red)	Fe_2O_3
Hematite (specularite)	Fe_2O_3
Kaolinite	$Al_2Si_2O_5(OH)_4$
Muscovite	$KAl_2(AlSi_3)O_{10}(OH,F)_2$
Quartz	SiO_2
Talc	$Mg_3Si_4O_{10}(OH)_2$

Which mineral is in each product? (Choose 1 mineral per product)

Product #	Products	Associated Mineral Name
  	Toothpaste, Cheerios & Antacid	
 	Glass & Sandpaper	
 	Table Salt & Road Salt	
	Jewelry	
 	Baby Powder & Makeup	
	Pencils	

	Drywall & Plaster	
	Sparkly Eye Shadow	
	Blush	
	Car Battery	
 	Porcelain	
	Copper Wire, Pennies & Matches	
	Aluminum Foil	
	Fertilizer	
	Mud Flap of Truck	

The Economics of Minerals:
Rechargeable Batteries and Mineral Resource Use

Learning objectives

By completing this activity and the homework, you will:

- Identify the mineral resources used in rechargeable batteries.
- Describe overall trends graphed for production and value (price) of nickel, cadmium, lithium, and lead, and identify changes in trends and/or anomalous features in the graphs.
- Explain trends, changes over time, and anomalies in terms of mine production, demand, recycling, changes in battery technology, regulation due primarily to health concerns, and/or population growth.
- Use a concept map to interpret the complex relationships among consumers, producers, regulating agencies, and the environment in a global context.
- Examine your own consumer behavior and judge the impacts of this behavior on sustainability.

Introduction

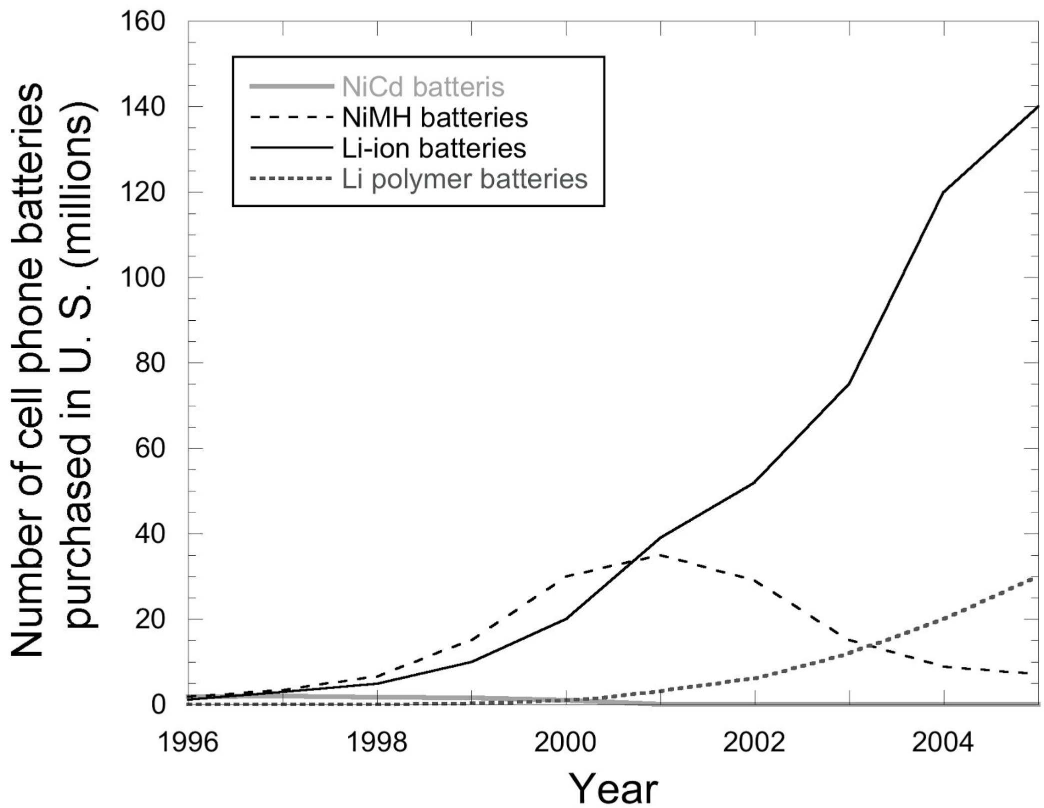
Mineral resources are important because they are used to make products. Thus consumers drive the quest for mineral resources, and economics play a large role in whether and how much minerals are mined.

In this activity, you will consider the mineral resources used to make rechargeable batteries, and the economic factors and consumer choices that influence the supplies of these mineral resources.

You need to know that there are five main types of rechargeable batteries: acid-lead, NiCd (nickel cadmium), NiMH (nickel metal hydride), Li-ion (lithium ion), and Li-polymer (lithium polymer).

Part 1A. Changing technology: cell phone batteries

In this part, we'll look specifically at batteries themselves. Use the graph below, which shows the number of cell phone batteries purchased annually in the United States, to answer questions 1–3.



1. Summarize in what ways the number of cell phone batteries has changed since 1996. You can write different answers for the different types of batteries.

2. Why do you think that the number of batteries used has changed?

3. The graph shows consumption of cell phone batteries in the United States. What do you think a graph showing global consumption would look like? Why?

Part 1B. Changing technology: car batteries

One important characteristic of batteries is their energy density. This tells how much energy (in Watt-hour) is contained is in a given mass (kilogram). We want a battery that has a lot of energy for its size. Cost is another consideration. Safety is also a factor; we want batteries that do not cause laptops (or cars) to explode! The table shows energy densities and approximate costs of the different types of rechargeable batteries. Use the table to answer questions 4–8.

Rechargeable battery type	Energy density (Wh/kg)	Approximate battery cost
Lead-acid	30–50	$25 (6 V)
NiCd	45–80	$50 (7.2 V)
NiMH	60–120	$60 (7.2 V)
Li-ion	110–160	$100 (7.2 V)
Li-ion polymer	100–130	$100 (7.2 V)

Standard car batteries are lead-acid batteries. Batteries in hybrid-electric and plug-in-electric cars are either NiMH (for example, in the Toyota Prius) or Li-ion (for example, in the Chevy Volt).

4. Why are the newer electric cars using Li-ion batteries?

5. Why are lead-acid batteries still used in gasoline-engine cars?

6. In what ways do you think demand for lead, lithium, and nickel will change in the future? Explain your reasons.

7. Each car battery contains about 21 lbs. of lead. Car ownership is expanding in developing countries. In 2011, there were 75 million motor vehicles owned in China (there were about 240 million owned in the United States). China is expected to own 200 million motor vehicles by 2020. Assuming these vehicles will be standard gasoline-burning cars, each with an acid-lead battery, how much more lead (in tons) would need to be produced to meet the demand? To answer this, you need to know that there are 2204.6 lbs. in one metric ton.

8. List several consequences that might arise from the increased demand.

Part 2A. Using the concept map to make predictions

The elements nickel and lithium are used in the batteries we just considered. Let's consider what factors might impact the amount of nickel and lithium mining.

The following events affected the price/value of either nickel or lithium, because they affected either the supply or demand of these commodities.

9. Based on the concept map, how (and why) should each of the following events affect either nickel (Ni) and/or lithium (Li) demand or supply and price?

   Example: The only two lithium mines in North Carolina closed: 1986 and 1998
   This should reduce Li production, which would lower supply and thus increase Li price.

   - First commercial Li-ion battery: 1991

   - EPA classifies cadmium as Group B1 probable human carcinogen (cadmium is used with nickel in NiCd batteries): 1992

   - Three new nickel mines/plants open in Australia: 1998–2004

   - First commercial HEV (hybrid-electric car) introduced to U.S. market: 1999 (until 2008, all used NiMH batteries)

- Global recession December 2007–2009

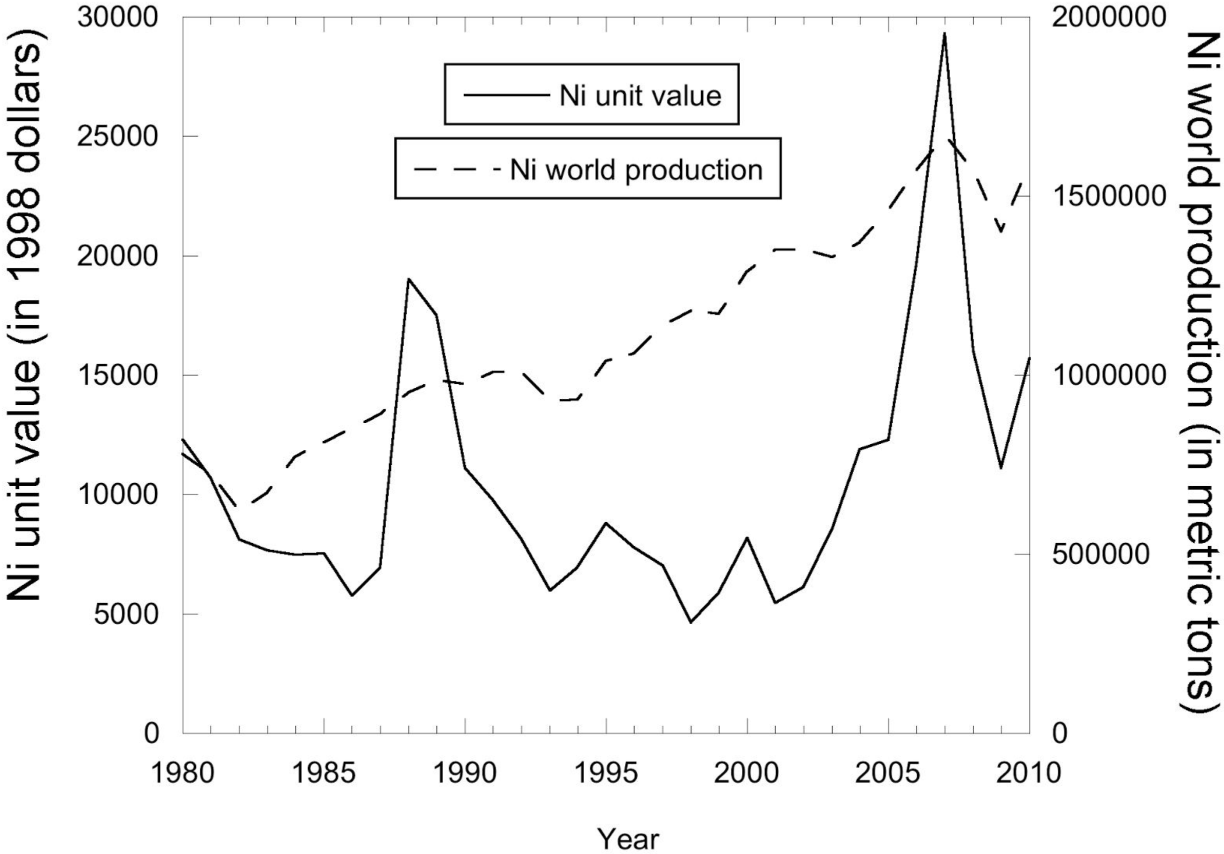
These other events also may have impacted either lithium or nickel demand, supply, and price:

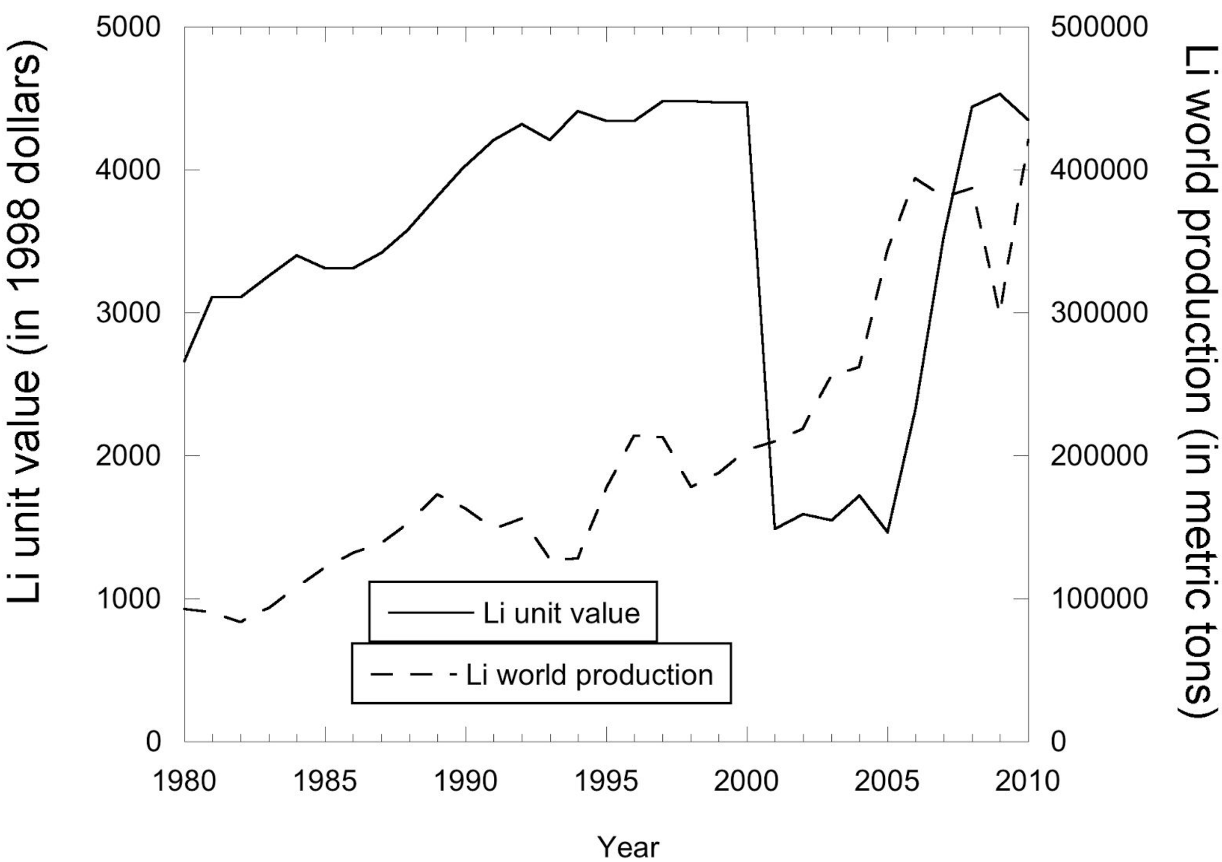
- First NiMH batteries appeared in consumer goods: 1989
- Congress passes Mercury Containing and Rechargeable Battery Act (facilitates recycling of NiCd batteries): 1996
- Large exports of scrap metal (containing nickel) from Russia: 1996–1998
- Improvements in PAL processing technology (used for nickel): 2000
- American Recovery and Reinvestment Act—money spent on rechargeable battery technology (including opening a Nissan LEAF [electric car] plant in 2010): 2009
- First plug-in electric vehicles (LEAF, Volt: these use Li-ion batteries): 2010

Part 2B. Testing your predictions against data

Use the graphs of nickel (Ni) and lithium (Li) production (production = mining and recycling) and value (price) to answer this question. The values are given in price (in 1998 dollars, to remove effects of inflation) per metric ton.

10. Pick two predictions you made in #9. Explain how data presented in the graphs of Ni and Li production and price support or refute your predictions.





Graphs to use for part 2B.

Data sources

Graphs in this activity were created by J. Branlund, using data from the following sources:

- Data Presented in the Graphs of Value/Price and Production are from Historical Statistics for Mineral and Mineral Commodities in the United States. USGS Data Series 140. Available at http://minerals.usgs.gov/ds/2005/140/.

- Data on Number of Batteries and Metals in Batteries are from D. R. Wilburn (2008), "Material Use in the United States—Selected Case Studies for Cadmium, Cobalt, Lithium, and Nickel in Rechargeable Batteries," USGS Scientific Investigations Report 2008-5141. Available at http://pubs.usgs.gov/sir/2008/5141/.

- Battery Energy Density and Cost is from Isidor Buchmann, *Batteries in a Portable World.* Available at http://www.buchmann.ca/.

Rare Earth Elements: Supply, demand, consumption, price

Rare Earth Elements (REE) are extensively used every day in batteries, electronics, ceramics, and high-powered magnets, and they are vital for clean energy technologies as well. In this activity we will look at REE supply, and consumption and price data, and discuss possible future strategies for balancing REE supply and demand.

China supplies the majority of the world's REE. The Chinese government sets the maximum amount of REE that can be legally exported out of the country (i.e., **export quota**) each year. The following table shows the amount of the export quota each year for the years 2000–2010 (except for 2002, for which we have no data), and the price per ton of REE adjusted for inflation with respect to the value of U.S. dollars (USD) during 1998 (shown as 98$/t, which means 1998 dollars per ton).

Year	Total export quota (metric tons)*	REE price per ton** in USD during 1998, expressed as (98$/t)
2000	47,000	6,110
2001	45,000	5,330
2002	N/A	6,800
2003	40,000	5,450
2004	45,000	7,410
2005	65,580	5,500
2006	61,070	3,150
2007	59,643	4,160
2008	49,990	10,300
2009	48,155	7,100
2010	30,258	14,500

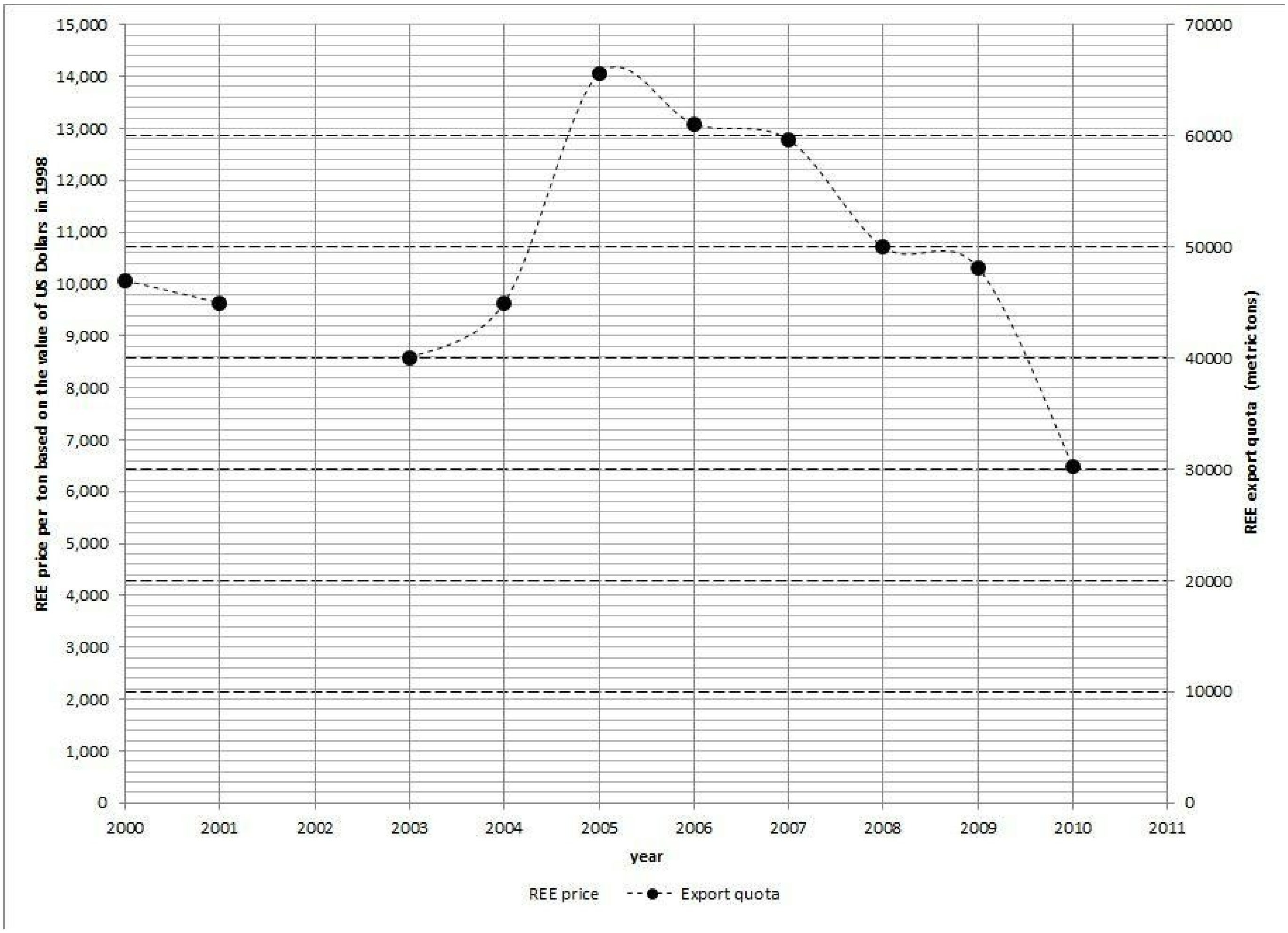
* Quota data from "China's Rare-Earth Production, Consumption, and Export Quotas for 2000 through 2011." (Tse, Pui-Kwan, 2011, China's Rare-Earth Industry: U.S. Geological Survey Open-File Report 2011–1042, 11 p.) Data from 2005 onward show total export quota for domestic producers and traders, plus Sino–foreign joint ventures.

** Price data from: "U.S. Geological Survey, 2011, REE statistics," in Kelly, T. D., and Matos, G. R., comps., "Historical Statistics for Mineral and Material Commodities in the United States," U.S. Geological Survey Data Series 140, at http://pubs.usgs.gov/ds/2005/140/.

1. The amount of REE allowed to be exported out of China is plotted on the graph below. Plot the REE price from the above table (the third column) on the same graph, using connected symbols.

Please use a different symbol (not a filled circle) for your plot, and indicate your symbol on the legend below the graph.

Note: This graph has TWO vertical axes. The vertical axis on the left indicates the price of REE expressed in terms of dollars per ton adjusted for inflation (98$/t). Use this axis for the data you need to plot. The vertical axis on the right shows the amount of REE export quota from China for the years listed. This data is already plotted for you.

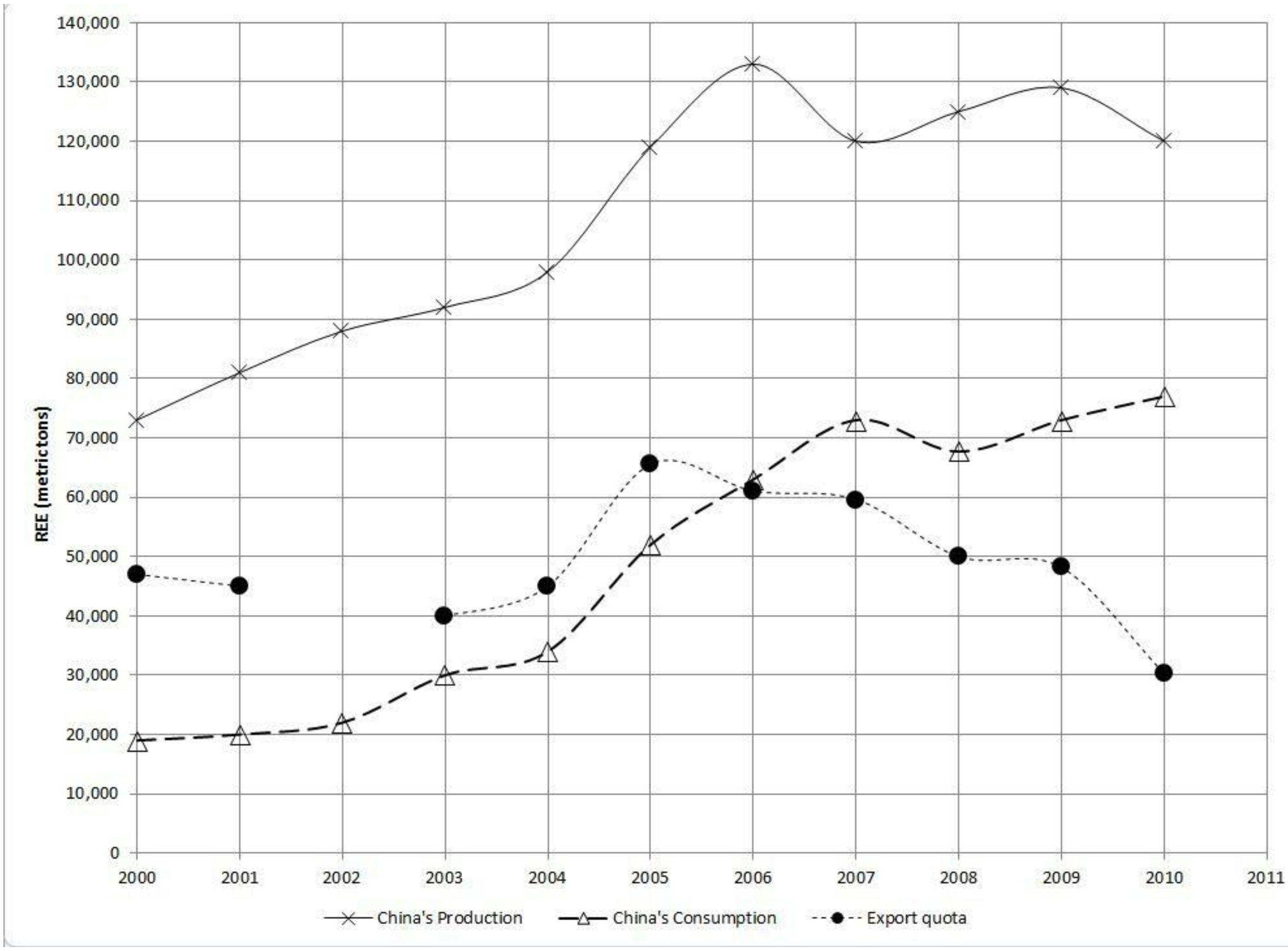


Answer the following questions based on the plot shown above:

2. The trend of the REE export quota is shown by black dots and the dotted line. By how much was the REE export quota reduced between 2005 and 2010?

3. When did the price of REE reach its lowest value? What was the approximate lowest value for REE?

4. Based on this graph, what can you say about the relationship between the REE export quota out of China (supply) and the price of REE?



5. China's REE production (Xs), consumption (open triangles), and export quota (filled circles) for 2000–2011 are shown in the above chart. Why do you think China is currently reducing its export quota? Give two reasons.

Rare Earth Element	**Partial list of uses in clean energy technology fields**				**Demand* (Tons)**	**Supply* (Tons)**
	Magnets (to generate electricity, in wind turbines, hybrid cars, etc.)	**NiMH batteries in some hybrid cars**	**Phosphors in energy-efficient light bulbs (CFL)**	**Catalysts in cars (catalytic converters, to reduce pollutants)**		
Lanthanum		X	X	X	41,200	30,500
Cerium		X	X	X	43,900	38,400
Praseodymium	X	X		X	9,800	7,000
Neodymium	X	X			27,000	24,400
Europium			X		400	390

*Data from Roger Bade (2010), "Rare Earth Review: Is the Hype Justified?" http://www.slideshare.net/RareEarthsRareMetals/libertas-rareearthreview

6. Some common uses, demand, and supply, for five of the rare earth elements are shown in the above table. You'll notice that supply and demand are out of balance. What can consumers, REE producers (e.g., mining companies), and technology manufacturers do to reduce the imbalance, and how will these actions affect the adoption and use of clean-energy technologies? Create a concept map to illustrate your answers.

Optional end-of-unit reflection question (this can also be used as a post-unit homework assignment or can be used as a unit-based question for an exam)

7. Describe two measures that you can personally take to reduce the supply/demand imbalance of REEs. Explain how those measures could either increase REE supply or reduce REE demand or both.

Humans’ Dependence on Earth's Mineral Resources
Unit 3
Mining and Mining Impacts

Part II: Ore Grades, Waste, and Remediation

Learning objectives

- Use spatial and quantitative skills to interpret geological information.
- Calculate the amount of metals obtained and the amounts of waste created through mining.
- Evaluate the impacts of various factors on an ore's cut-off grade.
- Compare the pros and cons of continuing mining in an area and weigh different remediation approaches.

Assignment Directions

The class will divide into small groups. Each group will work on a different section of this assignment. There are three different sections.

Once your group completes a section of the assignment, please see me for the next section.

You will have a total of 20 minutes to complete this activity.

Humans' Dependence on Earth's Mineral Resources
Unit 3
Mining and Mining Impacts

Part II: Ore Grades, Waste, and Remediation

Section I: Mining and Waste

Golden Sunlight Mine (GSM), near Whitehall, Montana, opened in 1983 and is still open today. It is one of the properties owned by the Canadian company Barrick Gold Corp. Take a look at the attached satellite image of Golden Sunlight Mine. Some remediation (slope stabilization) has been done by planting and growing vegetation on the west side of the West Waste Rock Dump Complex and on the northeast side of the East Waste Rock Dump Complex.

1) On the attached satellite image, use a marker to denote the boundaries of mining areas (e.g., draw a line around the Mineral Hill Open Pit Mine area, etc.) and a different color marker to denote the boundaries of waste areas (e.g., draw a line around the West Waste Rock Dump Complex, etc.).

2) Use the boundaries you created to estimate the approximate percentage of land surface area that is used for actual pit mining as opposed to the storage of mining waste products (including both waste rock and tailings). The approximate percentage of land surface used for pit mining as compared to that used in mine waste storage is:
    a. 90–100%
    b. 70–85%
    c. 45–55%
    d. 15–30%

3) For a sense of scale:
    a. Estimate the number of acres inside Tailings Impoundment #2 using the scale box (100 acres) on the map.

    b. If an American football field, including the end zones, is about 1.32 acres, approximately (mathematically) how many football fields would fit inside Tailing Impoundment #2? Show your calculations here.

4) Why might Tailings Impoundment #1 look different than Tailings Impoundment #2?

5) The Montana Department of Environmental Quality (DEQ) has recently received an application from GSM to amend their operating permit. This would include adding one new pit northeast of the mine and extending the larger Mineral Hill pit, although within the previous permit boundary. This additional mine area would extend the life of the mine for two years to 2017, allowing the company to continue to explore

the area without closing. The additional mining would result in an estimated 4.2 million tons of ore and 52.6 million tons of non-ore rock (waste).

a. What is the percentage of ore to waste (by weight) for these new sections? Show your calculations here.

b. What might be some incentives of the DEQ and the community to approve the permit? What might be some incentives not to approve the permit?

Golden Sunlight Mine Satellite Image

Humans' Dependence on Earth's Mineral Resources

Unit 3

Mining and Mining Impacts

Part II: Ore Grades, Waste, and Remediation

Section II: Ore Grades and Mining

The **grade** of an ore is the concentration of the desired material within the rock. There is more metal (a higher concentration) in higher grade metal ores. Ore grades are often given in percentages or in units of ppm (defined below).

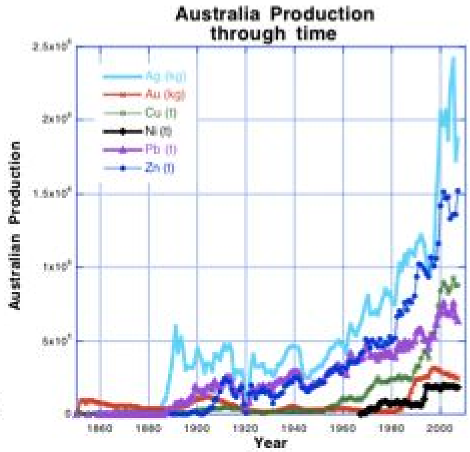
Percentages, which most of us are familiar with through our class grades, are actually a measurement of "parts per total parts." In the case of grades on an exam, if you received a 92% on your 100-point exam, you received 92 points out of a possible 100 points. This is similar to ores: If a nickel ore has a grade of 2%, it means there are 2 pounds of nickel for every 100 pounds of ore. It also means that there are 2 grams of nickel for every 100 grams of ore, etc., so long as the unit of comparison remains the same within the percentage calculation (pounds to pounds or grams to grams or ounces to ounces, etc.).

1) Some sources say that the average single family home in the United States uses about 420 pounds of copper within the plumbing, appliances, building wire, and more. In the twenty-first century, an average copper grade ore might be ~0.6%.
    a. How many pounds of 0.6% grade copper ore needs to be mined in order to obtain 420 pounds of copper? Show your work here.

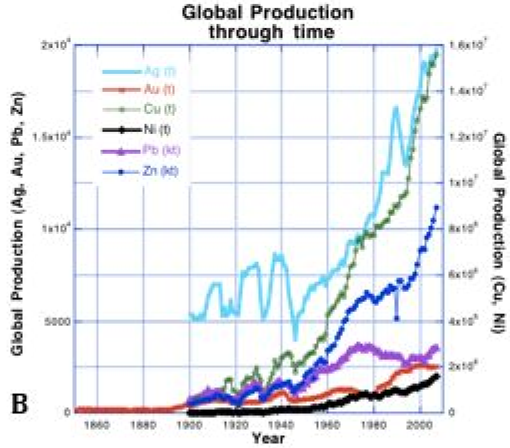
Another frequently used unit of measurement for ore grades is "parts per million" or ppm. Instead of finding the concentration per 100 parts, like the percentage, ppm finds concentration out of one million parts. This unit is used to represent metals that often occur in smaller concentrations. A gold ore with a 2 ppm ore grade would have 2 pounds of gold for every 1,000,000 pounds of ore. An equivalent unit is grams/ton (since there are 1,000,000 grams, or 10^6 grams, in a metric ton). Thus a 2 ppm grade gold ore would also have 2 grams of gold for every ton of ore.

1) A gold coin called a Krugerrand has approximately 31.1035 grams of gold in it.
    a. How many metric tons of 15 ppm grade gold ore need to be mined in order to get enough gold for a *single* Krugerrand? Show your work here. Remember that 1 metric ton = $1x10^6$grams.

    b. How much waste product (in metric tons) is created? Show your work here.

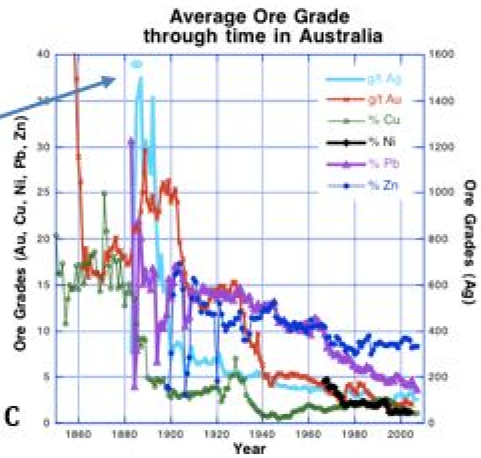


A



B

+ indicates off-the-chart values of 3506 g/t in 1884 and 2594 g/t in 1886.



C

The plots A and B above indicate the production of certain metals (Ag, Au, Cu, Ni, Pb, and Zn) in Australia (A) and globally (B) over the period from ca. 1850 to 2007 (where data is available). Plot C shows the average ore grade mined in Australia for these same metals over the same period.

2) Draw an arrow on each of the three plots above to indicate the general trend of the amount of production (A & B) and the grade of the ore (C).

3) If ore grades (the concentration of the metal within the ore) have decreased toward more recent times, yet production of the metal has increased, then what are the implications for:
   a. The amount of ore that must be mined to allow production of the metal to stay the same or to increase?

   b. The amount of waste rock and tailings produced from the processing of that ore?

4) List/explain at least three possible reasons why the ores grades have trended toward lower grade ores in more recent times.

Humans' Dependence on Earth's Mineral Resources
Unit 3
Mining and Mining Impacts

Part II: Ore Grades, Waste, and Remediation

Section III: Cut-off Grade, Mine Productivity, and Legacy Mines

Many aspects influence the financial productivity of any mine. Obviously the presence of the desired material is key, but both geological and nongeological elements influence the overall success of the mine. Some important factors, in addition to the strategy of the company and their management, include:

Resource Quality: Ease with which the ore can be mined, the type of mineral resource, the size of the ore deposit, ore grade (concentration of desired material within the rock)
Input Costs: Labor, energy, and water use; infrastructure and services; other materials used in the mining process
Macroeconomic Factors: Metal prices, ability to obtain credit and interest rates, exchange rates
Other Factors: Governmental permitting rules, financial resources, social and political factors

Together these factors determine whether a site is worth mining and/or whether a mine will stay open and, if so, for how long. They will also influence the extensiveness of the mine (how much land is mined), the amount of waste products created, the number of jobs maintained, and more. A mining company has some control over only some of these factors.

The **grade** of an ore is the concentration of the desired material within the rock. There is more metal (a higher concentration) in higher grade metal ores. Ore grades are often given in percentages or in units of ppm.

The **cut-off grade** of an ore is essentially the lowest grade of an ore that is worth mining. If the ore grade is less than the cut-off grade, then a mining company will not make money mining that ore. According to Fellows (2010), the cut-off grade of an ore is one of the main factors in determining the economics of the mine.

It might seem as if the cut-off grade of an ore is determined permanently at the time of exploration and mine opening, but actually the cut-off grade changes throughout the lifetime of the mine (and thus, changes the estimates of the amount of ore in a reserve). For example, if cut-off grade drops, the mine is now able to profitably extract metal from an ore with a lower ore grade (a lower concentration of metal in the ore).

1) For the factors listed below, note whether the cut-off grade would likely rise or fall ***and explain why***. The first one (a) is an example:

   a. Increased market price of the metal? Rise or **Fall**
   Explain:
   If the mine can receive more money for each ounce that they produce, then the extra costs of processing more lower concentration ore are worthwhile. Therefore an increased market price could lead to a lower cut-off ore grade.

   b. New beneficiation technologies? Rise or Fall
   Explain:

   c. Better (more equitable) labor agreements? Rise or Fall
   Explain:

d. Rising energy costs? Rise or Fall
Explain:

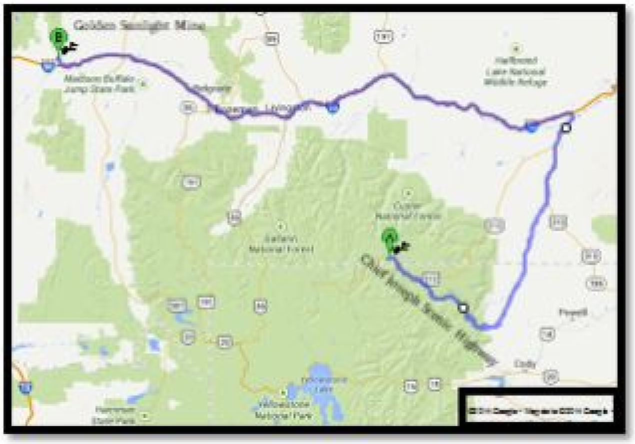
e. More stringent environmental regulations? Rise or Fall
Explain:

2) Many closed mines exist throughout the United States (and other countries). If the cut-off grade drops for ores once extracted from these legacy mines, what might happen to these old mines?

The Golden Sunlight Mine (GSM) near Whitehall, Montana, is relatively close to dozens of legacy mining operations. In the fall of 2012, GSM won an award from the U.S. Bureau of Land Management for helping to reuse materials from legacy silver and gold mines. The GSM partnered with other groups to remove and process the tailings from the legacy mines, deposit the reprocessed tailings into a more modern, lined, tailings pond, and reclaim the old site (all with proper permitting). The partners and related contractors benefit financially, the historic sites are cleaned up with a reduced amount of federal/state (taxpayer) expense, and new jobs are provided. In 2011–2012, GSM had at least 10 different contracts to bring in historic mine materials for processing, including from sites on public lands.

3) These same legacy tailings have been around for a long time and remained untouched for years. What factors might have changed to allow this type of “ore processing” partnership to exist today?

In 2010, the Montana Department of Environmental Quality (DEQ) proposed a plan for the cleanup of the McLaren Tailings Abandoned Mine Site just outside of Yellowstone National Park near Cooke City (“A” on map below). This area was noted to be contributing acid mine drainage to the Soda Butte Creek, which runs through a portion of Yellowstone National Park, and there were concerns about a possible failure of the tailings dam. As proposed in 2010, the plan was to remove approximately one-half million tons of mine waste from the site, most to be placed in a repository near the site, but of which about 20% (~68,700 tons) would be transported for gold processing at GSM. It was believed that for the DEQ/State of Montana, this would break even monetarily; the cost of hauling on this 640-mile round-trip route through both Montana and Wyoming (see highlighted highway section on map) to the Golden Sunlight Mine (“B” on map) would approximately equal the money made by selling the gold tailings, estimated to be $25–30 million.



The plan would require approximately 120 loads to be transported each week (Monday through Friday), averaging 24 round trips each day using double belly haul trucks with a capacity of about 40 tons for one summer (~14 weeks). As commercial hauling vehicles are not allowed in Yellowstone National Park, the trucks must take the longer route noted in the map above.

The tailings contain some substances that can be dangerous to humans or other organisms. Laboratory testing of the tailings (stabilized for easier hauling) indicated that values of cadmium, copper, iron, mercury, and silver were significantly above background levels; in particular, concentrations of iron and copper were above the target concentrations for residential exposure. However, the tailings were below the limits established by the Toxicity Characteristic Leaching Procedure and therefore not classified by the Environmental Protection Agency (EPA) as Hazardous Material.

In the end, this plan to transport the tailings to GSM was nixed based particularly on voiced concerns from Wyoming about the intense use of the Chief Joseph Scenic Highway (see on map above), which has very curvy sections and is one of the steepest roads in the area (up to 7% slope), to transport the tailings. Instead, the new plan calls for all the tailings material to be placed in the nearby repository, which was deepened in design in order to accommodate the total amount from the McLaren site.

4) Please explain some potential positive aspects of the proposal to haul the legacy tailings to GSM to extract the gold. In what ways would this have been a good plan?

5) Please explain some potential negative aspects of the proposal to haul the legacy tailings to GSM to extract the gold. In what ways might this not have been a good plan?

6) If you were a resident of Wyoming near this area, what concerns might you have had about this proposal to haul to GSM?

Humans' Dependence on Earth's Mineral Resources
Unit 3
Mining and Mining Impacts

Part II: Ore Grades, Waste, and Remediation

Sources/References

Plots and Figures

Section I:

"2010 Draft Environmental Assessment for the East Pit Project and Tailings Impoundment Raise: Golden Sunlight Mines, Inc." 2010. Montana Department of Environmental Quality, Environmental Management Bureau, and the USDI Bureau of Land Management. Downloaded from http://deq.mt.gov/ea/hardrock/goldensunlight/LetterandDraftEAGSM.PDF. (See for information on the East Pit Project and nearby borrow area, East Buttress Dump Extension).

"Barrick Golden Sunlight: Current and Future Operations—Mine Design, Operations, and Closure Conference." 2012. Downloaded from http://www.mtech.edu/mwtp/conference/2012_presentations/Seth%20Slatter.pdf. (See for information on future south possible extension of Mineral Hill and new northeast pit mine)

*Final Supplemental Environmental Impact Statement Golden Sunlight Mine Pit Reclamation, c*hapters 1 and 3. 2007. Montana Department of Environmental Quality and U.S. Department of Land Management. Downloaded fromhttp://deq.mt.gov/eis/hardrock/GoldenSunlightSEIS/finalSEIS.mcpx.

Google Earth for base map.

Section II:

Data for plots from: Mudd, G. M. 2009. "The Sustainability of Mining in Australia: Key Production Trends and Their Environmental Implications for the Future." Research Report No RR5, Department of Civil Engineering, Monash University and Mineral Policy Institute, Revised April 2009. Downloaded fromhttp://users.monash.edu.au/~gmudd/files/SustMining-Aust-Report-2009-Master.pdf.

Section III:

Map ©2014 Google – Map data

Other Sources of Information and Ideas (in addition to those listed above)

"2012 BLM Reclamation and Sustainable Mineral Development Award Winners." 2012. U.S. Department of the Interior Bureau of Land Management. Downloaded from http://www.blm.gov/wo/st/en/info/newsroom/extras/2012_blm_reclamation.html.

Byron, E. 2012. "New Partnership Finds Fortune in Golden Sunlight Tailings." *The Billings Gazette.* Downloaded fromhttp://m.billingsgazette.com/business/new-partnership-finds-fortune-in-golden-sunlight-tailings/article_7e4c0129-846c-52f5-8d05-f1a0282c1d9b.html.

Colnar, R. 2012. "Innovative Idea at Golden Sunlight Mine Benefits the Economy, the Environment, and the Mine." *Montana Mining 2012,* Montana Mining Association, pgs. 32–33. Downloaded fromhttp://www.montanamining.org/documents/newsletters/june_2012.pdf.

"Copper." Northwest Mining Association. Downloaded from http://www.nwma.org/education/copper_facts.htm on 10/10/12. (This website has since been changed.)

"Copper Uses." Viking Minerals. Downloaded from http://www.vikingmineralsinc.com/copper-uses.html.

Dunwell, M. A. 2010. "Draft Transportation Proposal Available for Reclamation Project near National Park." Montana Department of Environmental Quality. Downloaded from http://svc.mt.gov/deq/press/pressDetail.asp?id=1131.

Dunwell, M. A. 2010. "McLaren Tailings Reclamation Project to Redesign Mine Waste Disposal Facility." Montana Department of Environmental Quality. Downloaded from http://svc.mt.gov/deq/press/pressDetail.asp?id=1144.

"Fact Sheet—McLaren Tailings Reclamation Project December 2010: McLaren Tailings Reclamation Project Transportation Proposal Withdrawn, Waste Disposal Facility Redesigned." Montana Department of Environmental Quality, 2 pages. Downloaded fromhttp://deq.mt.gov/AbandonedMines/pdfs/ProjectDocuments/McLaren/FINAL%20Fact%20Sheet%20McLaren_12-10.

pdf on 10/10/12. And updated fact sheet appears here: http://deq.mt.gov/abandonedmines/mclaren.mcpx.
Farr, M. R. 1991. *Exploring for Copper Deposits. Hands-on Geology: K–12 Activities and Resources.* Edited by Macdonald, R. H. and Stover, S. G., SEPM, 105 pgs. Downloaded fromhttp://www.beloit.edu/sepm/Rocks_and_minerals/exploring_for_copper.html.
Fellows, M. 2010. "Gauging the Long-Term Cost of Gold Mine Production." *Alchemist* 60, pgs. 3–6. Downloaded fromhttp://www.lbma.org.uk/assets/Alch6001Fellows.pdf.
French, B. 2010. :Plan Would Have Moved Waste Rock to Extract Gold: DEQ Pulls Plug on Hauling Proposal." *Billings Gazette.*Downloaded from http://billingsgazette.com/news/state-and-regional/montana/article_0066e1a6-4261-5c43-83be-529c345fec66.html.
Gevock, N. 2012. "Golden Sunlight Mine Plans Expansion."*Helena Independent Record.* Downloaded fromhttp://helenair.com/news/local/golden-sunlight-mine-plans-expansion/article_70ea179c-09fe-11e2-922c-0019bb2963f4.html.
Golden Sunlight. 2012. "Mine Sites: Major Mining Operations around the World." *InfoMine.* Downloaded fromhttp://www.infomine.com/minesite/minesite.asp?site=goldensunlight.
"Krugerrand." Wikipedia. Downloaded from http://en.wikipedia.org/wiki/Krugerrand.
"Mineral Resources Answer Key." *2012 Teacher Symposium Lesson Plans.* The University of Arizona Geosciences. Downloaded from: http://www.geo.arizona.edu/sites/www.geo.arizona.edu/files/understanding%20ore%20deposits%20answers%20copy.pdfand http://www.geo.arizona.edu/node/264.
Peterson, L. 2012. "DEQ Receives Application to Amend Golden Sunlight Mine Permit." Downloaded fromhttp://metnet.mt.gov/Newslinks/I032C3690. Related press release by the same title found at:http://svc.mt.gov/deq/press/pressDetail.asp?id=1305.
Prevost, R. 2010. "Hauling Gold on the Chief Joe: Montana Officials 'Take Step Back' to Review Chief Joe Gold Transport Plan."*WyoFile.* Downloaded from: http://wyofile.com/2010/11/montana-officials-'take-step-back'-to-review-chief-joe-mine-waste-plan/on 10/10/12. Now at: http://wyofile.com/ruffin/montana-officials-'take-step-back'-to-review-chief-joe-mine-waste-plan/ although you need to enter the Wyofile website before searching.
Working Group on Geological Stocks of Metals. 2011. "Estimating Long-Run Geological Stocks of Metals."*UNEP International Panel on Sustainable Resource Management,* 32 pages. Downloaded fromhttp://www.unep.org/resourcepanel/Portals/24102/PDFs/GeolResourcesWorkingpaperfinal040711.pdf.
"World Class Deposits." *Copper Investing News.* Downloaded from http://copperinvestingnews.com/what-makes-a-world-class-copper-deposit.
"World Class Gold Deposits." *Gold Investing News.* Downloaded from http://goldinvestingnews.com/world-class-gold-deposits.