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SEG NEWSLETTER
www.segweb.org

APRIL 2018 NUMBER 113

SEG 2018 Conference
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Return to Bougainville—Reassessing the Mineral Potential of a Long-Forgotten Island

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Introduction

In June 2019, the population of Bougainville, a southwest Pacific island of 9,380 km^2, will vote on whether to remain an autonomous region of Papua New Guinea or become the world's newest nation. Proponents of an independent Bougainville are looking for sources of revenue to kick-start the island's economic development, including reopening the mothballed Panguna copper-gold mine (Barrett, 2017). However, significant local opposition to such a step remains (e.g., Davidson, 2018), so the future exploration prospects for the island are uncertain.

Panguna commenced production in 1972, as the world's largest copper mine, with total metal endowment of 18 billion pounds of copper and 30 million ounces of gold (historic production and remaining JORC-compliant resource; Collier et al., 2011; Bougainville Copper Limited, 2016). The operation closed 17 years later amid a prolonged campaign of sabotage by the Bougainville Revolutionary Army, stemming from social, environmental, and economic issues catalyzed by the mine (Denoon, 2000; Barrett, 2017). The Autonomous Bougainville Government and Papua New Guinea Government currently each own 36.4% of Bougainville Copper Limited, the publicly listed administrator of the mine after Rio Tinto divested their stake in the company during 2016.

Bougainville has 17 post-Miocene volcanoes, including the active or dormant Bagana, Balbi, and Loloru volcanoes (Blake, 1967). There are more than 60

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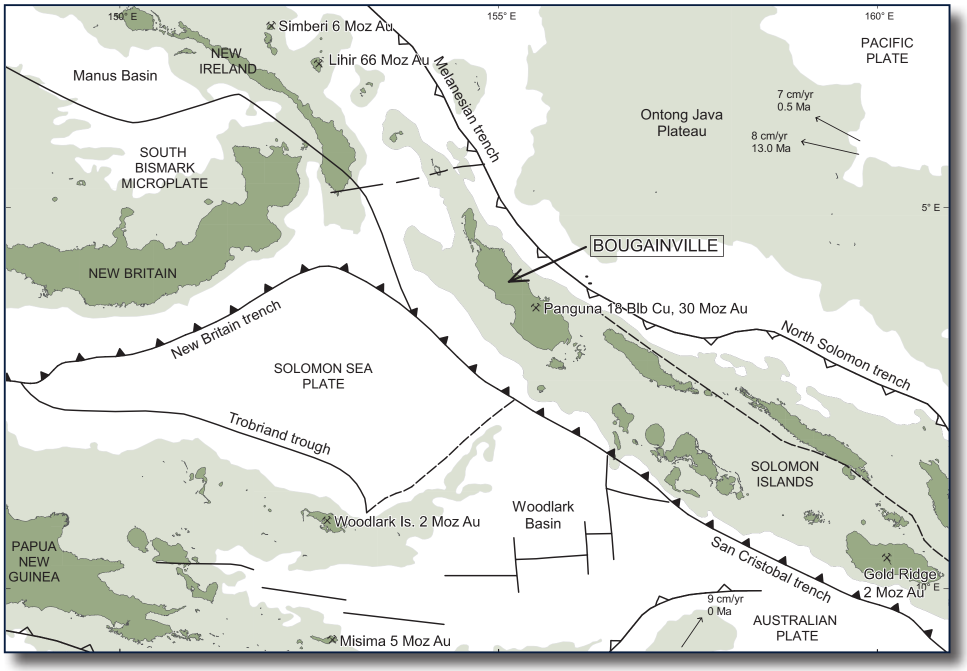

FIGURE 1. Tectonic setting of Bougainville and neighboring islands of Papua New Guinea and the Solomon Islands. Metal endowment of major deposits was calculated from resource and/or production data. Modified from figure 2 of Holm et al. (2016). Shaded areas occur above the 2,000-m bathymetric contour and show major oceanic crustal features.

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VIEWS

Antonio Arribas R. obtained his B.A. and M.Sc. degrees in geology from the University of Salamanca, Spain, and conducted his Ph.D. research at the University of Michigan. Antonio's career has been dedicated to the geology of and exploration for base and precious metal deposits. He has held a variety of positions in industry, ending with Vice President Geosciences BHP, and is currently a geoscience professor at Akita University, Japan. An active Fellow of SEG, Antonio served as SEG President in 2013, Vice President for Regional Affairs from 2006 to 2009, SEG Councilor from 2002 to 2004, and Thayer Lindsley Lecturer in 2001.

Making the Case for More, and More Practical, Economic Geology Education: The Point of View of an Exploration Geologist

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Introduction

The world is continually changing and the current pace of change is arguably faster than ever. In this context, is the education of economic geology keeping pace with the times? To clarify, I propose a broad, practical meaning for the term "economic geology," one that includes, in addition to ore[1] geology science, the relevant engineering, economic, environmental, and societal issues associated with mineral resources and mineral resource development—indeed, the broad variety of issues and areas of knowledge that an exploration geologist will face regularly throughout her/his career.

This Views article highlights the critical role that mineral resources and deposits play in society today and will play into the future. Against this backdrop, it appears that the contribution of mineral resources and their economic sector (the mining industry) to society is surprisingly misunderstood by the public at large, throughout the world. In a time of false news and Internet amplification, this lack of understanding is even more problematic. So are universities transmitting the knowledge on this issue in a way that is relevant to today's world? I argue that, with notable exceptions, economic geology education within earth science programs globally runs the risk of either focusing too narrowly on ore geology science or being a minor addendum within an earth science academic curriculum, if it is included at all. Both ends of the spectrum are inconsistent with the far-reaching impact that mineral resources and the extractive industries have on society, the economy, and the environment. Although not discussed in this article, it is obvious that the de facto lack of geology education in secondary schools worldwide has contributed greatly to the current situation.

Society Requires Mineral Resources

The development of humanity is marked by the increasingly complex use of the Earth's mineral resources. Starting with stones, clay, and bones and, with the onset of civilization, evolving to the use of metals (e.g., copper since at least 6,500 years ago; Fig. 1), this pattern has continued until today. We currently use

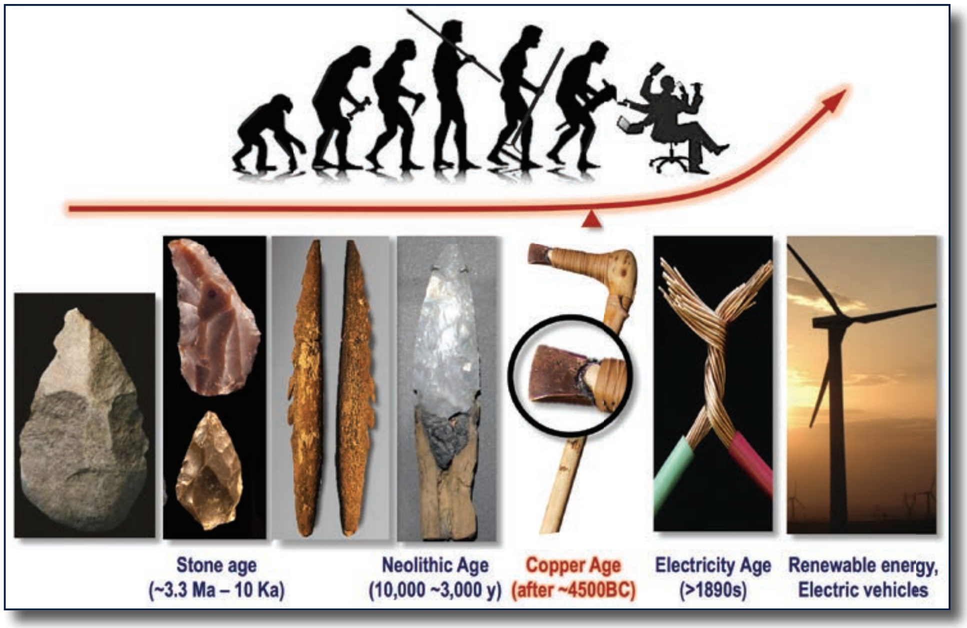

FIGURE 1. The role of minerals and metals in society. Human development is marked by the increasingly complex use of the Earth's mineral resources over a period spanning at least 3 m.y., but civilization is directly associated with the use of metals. Bottom images, from left: 1.76 Ma, Old Stone Age hand axe from Kokiselei, Kenya (Lepre et al., 2011; photo: P.J. Texier, copyright MPK/WTAP); 315 Ka, Middle Stone Age flint artifacts from Jebel Irhoud, Morocco (Richter et al., 2017; photo: M. Kamal, CC-BY-SA 2.0); ~17 Ka Magdalenian harpoons from Cova de les Cendres, Spain (Román and Villaverde, 2012); Neolithic flinstone dagger from Germany (photo: Archäologisches Landesmuseum Konstanz, CC BY-SA 2.5); replica of a ~3300 BCE copper axe from the Ötzal Alps, Austria-Italy border (South Tyrol Museum of Archaeology, photo: Bullenwächter, CC BY 3.0). Photos not to scale. "Evolution of man" silhouettes modified from N. Sinegina, after original photo by M. Cernuda (CC-BY-SA 4.0).

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[1] This contribution discusses ore mineral resources—that is, mainly metals, and not hydrocarbons (e.g., oil, gas, and coal).

a greater quantity and variety of metals than ever before (Figs. 2, 3). Barring an unforeseen disruption, this trend will not change in the near future; as the global population increases, living standards continue to improve (particularly in the developing world), and new technologies materialize. Indeed, some of these new technologies are widely regarded as an integral part of the solutions to some of society's most pressing concerns (e.g., the switch to green energy sources; Fig. 4).

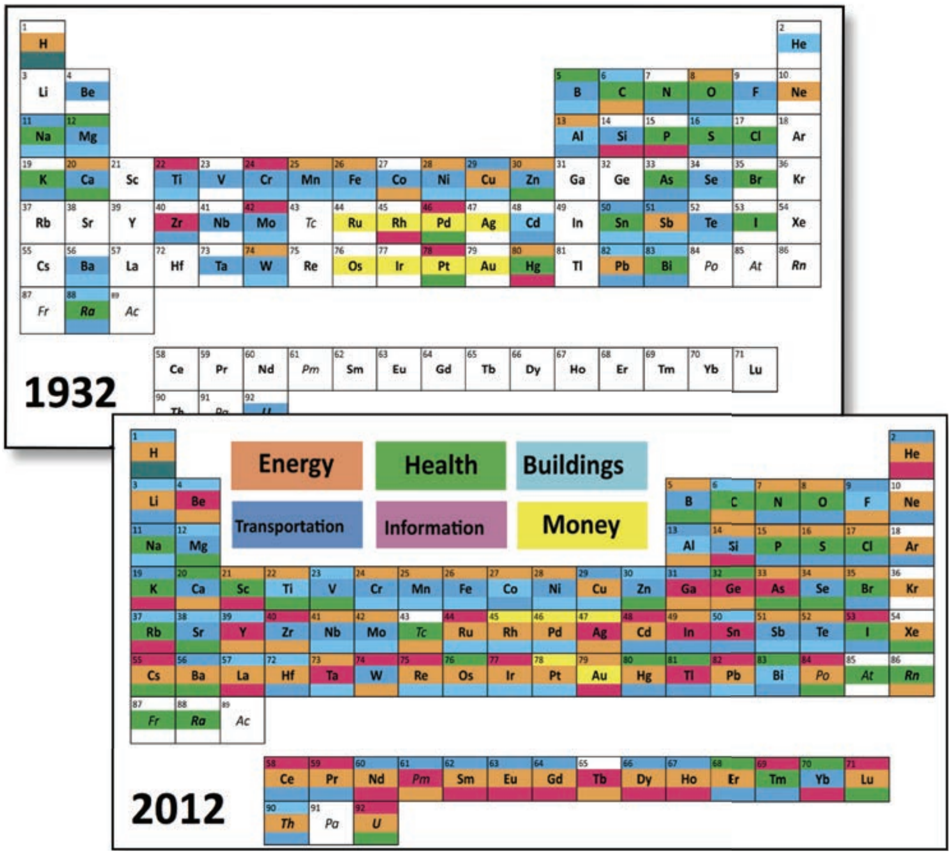

FIGURE 3. Major uses of the naturally occurring elements in 1932 and 2012 (Price, 2013). There are more than three major uses for many elements today. For definitions and the main applications of the six general categories listed, see Price (2013).

While the topic of the future of mineral resources (and, by association, mining) is complex and subject to controversy, one thing is clear: we will continue to require more metals than recycling and more efficient production and consumption combined can deliver—at least in the near future. The evidence for such a critical new role for metals, particularly those needed for advanced technological applications, is around us every day. Industry (e.g., car manufacturers), national governments, and supranational organizations (e.g., the European Union) all have lists of essential "critical metals" and work toward ensuring a reliable supply to sustain their products or industries.

Thus, society will need to continue to explore for, discover, and develop additional mineral deposits. The challenge is anything but trivial. On the one hand, the magnitude of the task is daunting: for example, during the next 1.5 years China alone will consume an amount of copper (~18 Mt Cu) equivalent to over 100 years of production from the largest copper mine in the world, the giant Bingham Canyon open-pit mine in Utah. On the other hand, a thick web of technical, socioeconomic, environmental, financial, and political/regulatory issues make finding and developing these mineral deposits a particularly complex enterprise nowadays. Faced with such a significant challenge and lacking a detailed understanding of the issues, it's not a surprise that some people react by seeking alternative views and solutions that don't always follow facts or logic (see below).

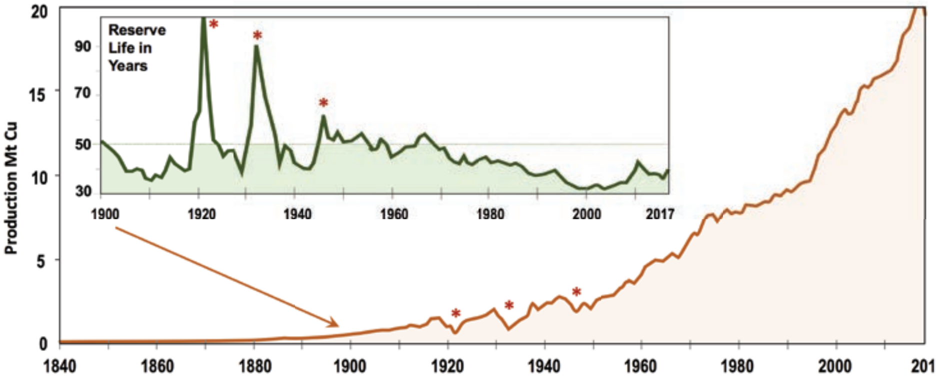

FIGURE 2. Evolution of global copper production since the mid 1800s (data from Mudd, 2010; 2010–2017 source data from USGS, https://minerals.usgs.gov/minerals/pubs/mcs/). Inset: Global reserve life (ratio of reserves over production) for copper, 1900–2010; asterisks indicate short periods of sudden drop in production, which translate into periods of artificially high reserve life (Schodde, 2010; 2010–2017 source data from USGS, https://minerals.usgs.gov/minerals/pubs/mcs).

What Society Reads and Hears (i.e., believes)

Despite their critical role, it appears that mineral resources are widely misunderstood and, all too often, society's views on the subject are disconnected from reality. Unfortunately, much of the public perception of mineral resource issues is based on incomplete information, biased interpretations, or outright misinformation. To illustrate these points, I have chosen two examples related to the broad question: "Are we running out of mineral resources?" A cursory Internet (image) search of this question[2] returns a web page full of sophisticated infographics showing countdown timers and abruptly ending bars marking the time until different commodities are exhausted. The associated titles and headlines

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[2] This raises a separate concern that has already been widely acknowledged: the danger of limiting and biasing global knowledge, whether voluntary or involuntary, due to the nature of the algorithms that control Internet searches (who looks beyond the entries shown in the first few Internet search windows?).

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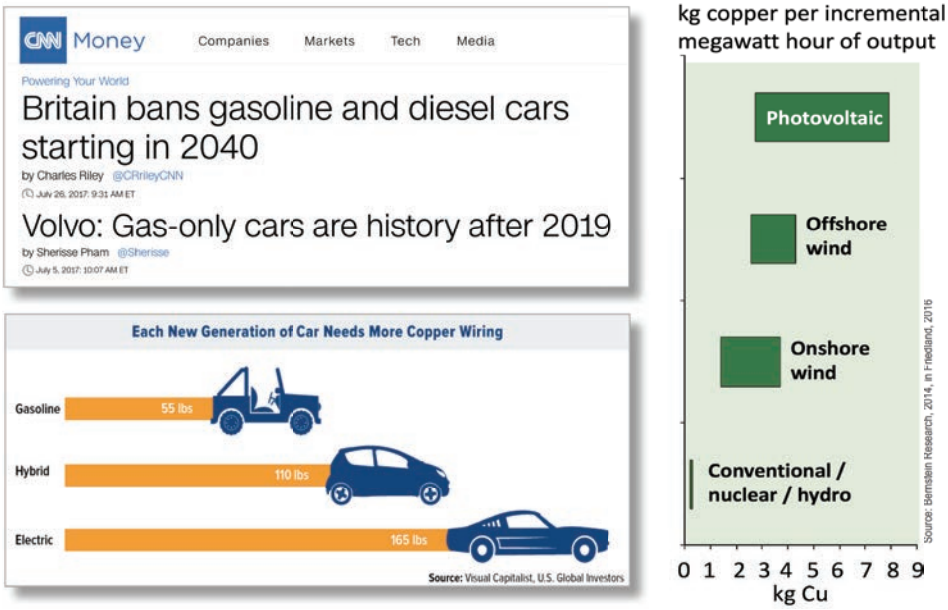
VIEWS — Making the Case for More, and More Practical, Economic Geology Education (continued)



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Powering Your World

Britain bans gasoline and diesel cars starting in 2040

by Charles Riley @CRrileyCNN

July 26, 2017: 9:31 AM ET

Volvo: Gas-only cars are history after 2019

by Sherisse Pham @Sherisse

July 5, 2017: 10:07 AM ET

FIGURE 4. The future of transportation is hybrid and electric, and it is being announced today. Both electric transportation and green energy require more copper; for example, the amount of copper required for increased power output from renewable sources is much greater than from conventional activity (source: Bernstein Research, 2014, in Friedland, 2016, p. 23).

are consistently dramatic: “Born in 2010: How much is left for me?,” “World stripped bare: How long will the world natural resources last?,” “If we fail to correct current consumption trends, then when will our most valuable natural resources run out?,” etc.

At least two of these widely circulated articles and graphics originate from allegedly reputable sources. One was published in issue 2605 of the international science magazine *New Scientist* in May 2007 (Fig. 5). In it, the author claims that, based on data by researchers from Yale University and the University of Augsburg, “if predicted new technologies appear and the population grows, some key resources will be exhausted” within what is graphically shown as an alarmingly short time frame (Cohen, 2007). Among the mineral resources covered, platinum, indium, and copper are particularly illustrative of the errors of interpretation contained in the article and the overall fallacy that this report represents.

According to the article, humankind should be running out of platinum within four years (15 years from 2007). However, despite production of 2,000 t of platinum between 2007 and 2017 and a metal price drop of 26%, the global reserves of platinum group metals have decreased only by 2.8%[3] (data from USGS, https://minerals.usgs.gov/minerals/pubs/mcs/). Likewise, according to this report we should have run out of indium sometime between 2012 and 2017. Never mind that, as a key component of indium tin oxide (ITO), this metal has been present as a transparent thin film conductor in the touch screen displays of every smartphone and tablet manufactured since then—including the 1.2+ billion iPhones sold by Apple alone since the product’s release in June 2007, barely a month after publication of the *New Scientist* article.

The second article and infographic selected were titled “Global resources stock check” and appeared in a June 18, 2012, article from BBC Future (www.bbc.com/future/story/20120618-global-resources-stock-check). In this report, the world supplies of indium, antimony, and copper, just to choose three, were projected to last through 2024, 2020, and 2044, respectively. I would argue that nothing but common sense is needed to believe that by the time of the Paris Olympiad in 2024, ITO-based transparent thin film conductors (or a new, and likely superior, substitute) will continue to be present in digital displays and thin-film photovoltaic cells, among many other applications. As for antimony, how do we reconcile the prediction that we should have only two years left of the metal now when, after production of 1.1 Mt between 2011 and 2017, global reserves remain unchanged within the 1.5- to 2.1-Mt range that has existed every year since 1997, when the U.S. Geological Survey started to record reserve estimates? In other words, for the time being and for the foreseeable future, the reserves of this metal are controlled by economics, technology, geopolitics, etc., and not by absolute limitations of availability in nature.

The case for copper is particularly relevant, since this metal will play a vital role in green energy and the transportation of the future. Both the BBC Future (2012) and *New Scientist* (2007) reports agree on a life span for copper between 30 and 40 years, a range which is consistent with the copper reserve life estimates of the past 30+ years. However, excluding three short periods of exceptionally low copper production (immediately following WWI and WWII, and during the peak of the Great Depression), the fact is that the reserve life for copper has remained unchanged within a 30- to 50-year band for the past 120 years (Fig. 2 inset; Schodde, 2010). This is despite a greater than 4,000% increase in production (Fig. 2)—simply

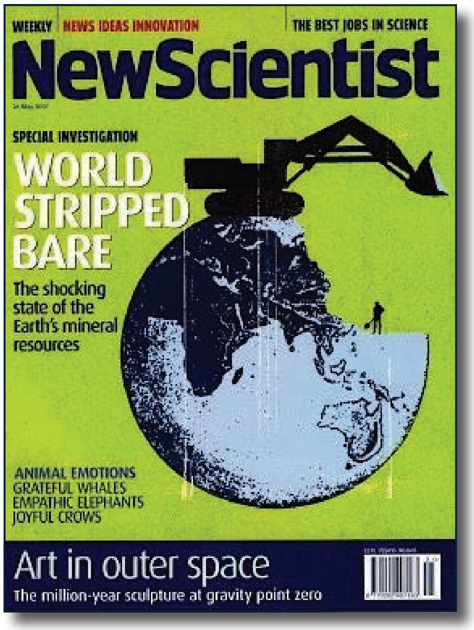

FIGURE 5. Cover of issue 2605 of the international science magazine *New Scientist* (May 26, 2007).

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[3] Note that a commodity price decrease directly impacts the estimation of reserves, as less material is profitable to be extracted and produced.

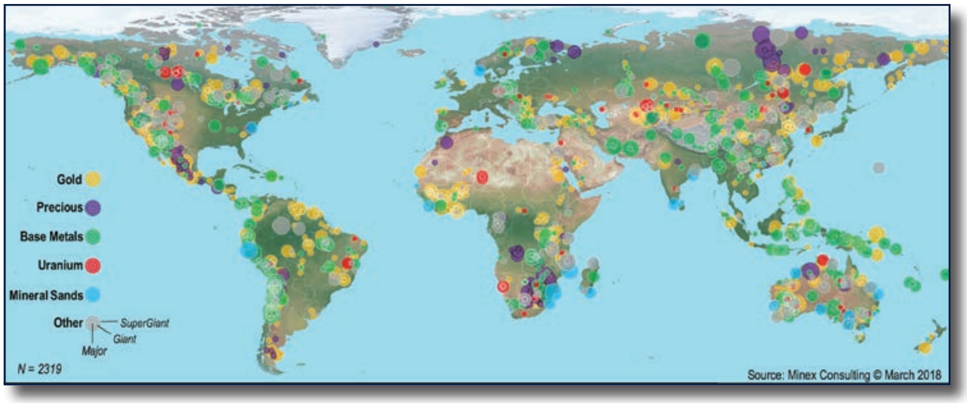
put, the world is not going to run out of copper anytime soon!

Reserves vs. Resources: Definitions Matter

Naturally, the problem here is the complete lack of understanding by the authors—and their editors—of the difference between mineral reserves and mineral resources, a concept basic to anyone familiar with mineral deposits.[4] I would argue that, in this era, all university-trained geologists, not just those specializing in economic geology, should learn this difference, just like they learn the difference between contact and regional metamorphism or between a silicate and a carbonate rock. Furthermore, I would argue that all students of fields with a relation to mineral resource issues (see below) should become familiar with such basic concepts early in their curriculum.

The Business of Exploration

To better understand the meaning of the copper reserve life estimates and the key underlying concept (mineral exploration), one should examine the cumulative production and reserve profiles (Schodde, 2010, p. 10) together with a record of deposit discovery (Fig. 6). For example, all the metals contained in the deposits shown in Figure 6 were not mineral reserves or identified resources prior to 1950; they all belonged to the undiscovered resource category. Yet, upon discovery, the in situ value at today's prevailing metal prices of these aptly termed "hypothetical" or "speculative" resources reached 18 trillion dollars (US$), in the case of copper alone![5] It's no wonder, perhaps, that the public at large finds it difficult to understand the business of mineral exploration. As with other basic concepts that require specialized training but have a broad impact on society, all geologists should be adequately educated about the basics of mineral exploration.



Source: Minex Consulting © March 2018

FIGURE 6. Visualizing the nature and economic impact of mineral exploration. Significant mineral discoveries since 1950 (R. Schodde, written commun., 2018; based on data in Schodde, 2017). Includes major, giant, and supergiant gold, base metals, and other mineral deposits; excludes bulk minerals (bauxite, iron ore, coal, phosphate, and potash). Every pound of copper and ounce of gold, etc., in the deposits was a hypothetical or speculative resource prior to 1950; the in situ value of copper alone discovered since 1950 is US$ 17.9 trillion at today's prevailing prices (see text).

Analysis and Recommendations

In the paragraphs above I have tried to highlight the critical role that mineral resources play in society today, including some key concepts that I believe need to form part of geology curricula everywhere. Unfortunately, and I don't think I am being too negative, this role and the associated factual information are all too often lost within media (news sources as well as social media) permeated by biased views and misinformation. For these reasons, I believe that higher education today, especially during the early years, needs to be less about transferring facts and hard knowledge and more about helping students gain perspective, distinguish between sources of information, be able to plan and conduct research, and communicate knowledge. As for economic geology education, prior and in addition to ore geology science, it must include adequate attention to the economic, environmental, and societal issues associated with mineral resources and mineral resource development. While providing such a context has always been necessary, for the reasons discussed above I believe it is urgent today. Without it, the ability of students to understand their own future roles within academia, industry, or society will be limited, and their ability to communicate more widely with society will also be limited.

In this context, I conducted an informal survey on the economic geology education of graduate students at Akita University from resource-rich countries. The survey, which included data between 2004 and 2016 from earth science programs in southern Africa (including Mozambique, South Africa, Zambia, Botswana, and Zimbabwe), identified several strengths and a few weaknesses. The strengths included (1) teaching of typically two economic geology classes (introductory and advanced) during the four- or five-year university programs, (2) mapping classes that included a minimum of 3 weeks of combined field camps, and (3) mineral exploration classes of variable depth taught at all schools. Among the weaker points, the economic, environmental, political, and societal context (the "big picture") of economic geology was, for the most part, missing or covered late in the program. From my experience, the situation in these countries is representative of much of the rest of the world.

Among the recent textbooks or publications that provide the necessary broad, practical view of the topic of mineral resources, I would like to highlight the following: (1) "Future of Mineral Resources" by Arndt et al. (2017; see above), (2) *Mineral Resources, Economics and the Environment* by S. Kesler and A. Simon (2016), (3) *Geology of Mineral Resources*

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[4] For a useful and timely discussion on the issue of mineral resources vs. reserves, particularly in the context of this discussion, the reader is referred to Arndt et al. (2017). This publication sprung mainly from an interest by the authors to set the scientific record straight after an earlier issue of the same, otherwise well-respected publication presented an alarming scenario on the future of mineral resources on the basis of poorly defined theoretical models unconstrained by factual data on reserves, resources, or the record of exploration discovery.

[5] As estimated by R. Schodde (written commun., 2018), 2,710 Mt Cu has been discovered since 1950 in deposits where copper is the primary metal (price applied US$6,600/t Cu, or ~US$3.00/lb Cu). It should be noted that, due to economic, social, and environmental concerns, not all of this metal is mineable; in addition, the cost of discovering, mining and processing, and the time delay between metal discovery and sale means that the net value of the metal is significantly lower.

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by M. Jébrak and E. Marcoux (2015), and (4) *Earth Resources and the Environment* by J. Craig, D. Vaughan, and B. Skinner (2011). I believe an introduction to the subject matter in any of these publications is of direct benefit to all earth science students, as well as students in environmental, sustainability, engineering, economics, and policy/government programs that deal directly or indirectly with natural resources. For geology students, once the big picture view is provided, specialized economic geology courses can then focus on ore geology science and advanced ore-forming processes. Indeed, presenting the big picture and the relevance of economic geology may attract more students to the field.

The second recommendation concerns the degree of attention given to economic geology education in earth science programs globally, particularly in many of the first-world countries I am familiar with. Although I don't have the detailed evidence to prove it, I firmly believe that students in many of these programs are not receiving the level of exposure to economic geology that the topic deserves and a well-rounded education demands. The association between mineral resources, mining, and the mining industry and the poor perception within segments of society of the latter may be partly responsible. Another reason may be the natural attention given to other earth science fields that are perceived as more relevant at a given time or geographic location.

Whatever the reason, the diminished role of economic geology in earth science education is evident simply by looking at the contents of some of the most popular introductory geology textbooks. Counted by a straightforward measure—the number of pages dedicated to the subject—only between 1 and 3% of the content of these otherwise exhaustively researched and beautifully written and illustrated books deals with mineral resources, including resources and society, formation and types mineral deposits, mining, etc. (e.g., Marshak, 2015; Tarbuck and Lutgens, 2015). I would argue that coverage several times greater is appropriate, not only because of the timely and far-reaching impact of economic geology within society, but because economic geology deals with the end product of the widest possible spectrum of geologic processes over the complete evolution of Earth, and ore deposits provide a record of this evolution.

In conclusion, earth science students must receive the proper training and develop the skills necessary to communicate effectively with other scientists and with the public in general, whether it be about natural hazards or mineral resources. In the absence of the necessary technical background and the skills or interest, professionals from other fields, typically without adequate training or understanding, will take over, dominate the discussion, and set the agenda, often with poor results.[6]

As for the issue of natural resources, because of their significance to society, earth science programs globally should ensure that all students receive a basic amount of economic geology instruction with a syllabus that reflects the relevant temporal or geographic issues and priorities. This may be the topic of a separate Views column, but I believe this goal is best achieved by involving professionals from industry or with adequate industry experience in the education process.

Acknowledgments

Richard Schodde (MinEx Consulting) generously provided unpublished data on mineral deposit discovery, including Figure 6. Review comments by Jeff Hedenquist, John Thompson, and Alan Besette greatly improved this contribution. The interest and enthusiasm of Akita University Faculty of International Resource Sciences short-stay and graduate students is always a source of energy and motivation.

REFERENCES

Arndt, N.T., Fontboté, L., Hedenquist, J.W., Kesler, S.E., Thompson, J.F.H., and Wood, D.G., 2017, Future global mineral resources: Geochemical Perspectives, v. 6, 171 p.

BBC Future, 2012, Global resources stock check: Report and infographic, www.bbc.com/future/story/20120618-global-resources-stock-check.

Cohen, D., 2007, Earth's natural wealth: An audit: New Scientist, no. 2605, p. 34–41.

Craig, J., Vaughan, D., and Skinner, B., 2011, Earth Resources and the Environment, 4th ed.: Upper Saddle River, New Jersey, Pearson Prentice Hall, p. 508.

Friedland, R., 2016, Producing strategic minerals to sustain an urbanizing planet: World Materials Forum, Nancy, France, June 9, 2016, Oral presentation.

Jébrak, M., and Marcoux, E., 2015, Geology of mineral resources: St. John's, Geological Association of Canada, 668 p.

Kesler, S.E., and Simon, A.C, 2016, Mineral resources, economics and the environment, 2nd ed.: Cambridge, Cambridge University Press, 446 p.

Lepre, C.P., Roche, H., Kent, D.V., Harmand, S., Quinn, R.L., Brugal, J.P., Texier, P.J., Lenoble, A., and Feibel, C.S., 2011, An earlier origin for the Acheulian: Nature, v. 477, p. 82–85.

Marshak, S., 2015, Earth: Portrait of a planet, 5th ed.: New York, W.W. Norton and Company, 984 p.

Mudd, G.M., 2010, The "limits to growth" and "finite" mineral resources: Re-visiting the assumptions and drinking from that half-capacity glass: Sustainability Society, 4th International Conference on Sustainability Engineering and Science: Transitions to Sustainability, Auckland, Nov. 30–Dec. 3, 2010, Proceedings, 13 p.

Price, J.G., 2013, The challenges of mineral resources for society: Geological Society of America Special Paper 501, p. 1–19.

Richter, D., Grün, R., Joannes-Boyau, R., Steele, R.E., Rué, M., Fernandes, P., Raynal, J.P., Geraads, D., Ben-Ncer, A., Hublin, J.J., and McPherron, S.P., 2017, The age of the hominin fossils from Jebel Irhoud, Morocco, and the origins of the Middle Stone Age: Nature, v. 546, p. 293–296.

Román, D., and Villaverde, V., 2012, The Magdalenian harpoons from the Iberian Mediterranean, based on pieces from Cova de les Cendres (Teulada-Moraira, Valencian region): Quaternary International, v. 272–273, p. 33–41.

Schodde, R., 2010, The key drivers behind resource growth: An analysis of the copper industry over the last 100 years: Society for Mining, Metallurgy and Exploration Annual Meeting, Phoenix, Arizona, March 3, 2010, Oral presentation, www.minexconsulting.com/publications/mar2010c.html.

——2017, Long term trends in global exploration—are we finding enough metal?: 8th Fennoscandian Exploration and Mining Conference, Levi, Finland, October 31, 2017, Oral presentation, www.minexconsulting.com/publications/oct2017b.html.

Tarbuck, E.J., and Lutgens, F.K., 2015, Earth Science, 4th ed.: Upper Saddle River, New Jersey, Pearson, 793 p.

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[6] The researcher for the BBC Future (2012) report had impeccable credentials: an undergraduate degree from Oxford University and master's and doctorate titles from King's College London, but in music!