MINERAL RESOURCES AND *THE LIMITS TO GROWTH*

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In writing an editorial for this issue on mineral resources, I was immediately reminded of *The Limits to Growth* (Meadows et al. 1972), a book that I read avidly from cover to cover as a young post-doc. For anybody interested in humanity's effect on the environment and its near-term consequences, it is still a fascinating read. The authors summarised a computer model of the likely effects of sustained economic growth on the Earth and the human population. Based on historical data from 1900 to 1970, they observed exponential growth in total human population, resource consumption, food consumption, industrialisation and environmental pollution. They fitted exponential growth curves to the data and assumed in their "standard model" that there was a 250-year supply of all resources at 1970 rates of consumption. They then developed what they considered to be appropriate feedback loops between the different parameters, such as between resource consumption and rate of industrialisation, food consumption and available arable land, gross national product (GNP) per capita, and birth rate. These feedback loops were added to the model, which was constructed to project how the global system would develop out to the year 2100. The results were startling.

In the standard model, the global system collapses because of resource depletion, which leads to increased diversion of industrial capital into resource extraction, which, in turn, reduces industrial growth. The industrial system collapses for lack of investment, taking with it the service and agricultural systems. The global population continues to rise for a while and then declines as death rates increase due to lack of food and health services. When does this start to happen? According to the 1972 study … about 2015; global population starts to decline from around 2030. Of course, the authors recognised the large uncertainties and didn't put great emphasis on the timescale. But they did note that, even making large allowances for increased resource availability and improved industrial efficiency, collapse still occurred before 2100. If, for example, they double the amount of available resources, collapse would be delayed by a few years, but then occurs due to increased pollution (including climate change), which damages food production and the health of the population.

The Limits to Growth has been subject to intense scrutiny and criticism since its publication. By allowing consumption to increase exponentially but with fixed or slowly increasing resource availability, the authors ensured that the system would collapse at some point. Furthermore, it has been argued that the authors made insufficient allowance for technical innovation. Some of the detail (such as the GNP per capita of China) has been invalidated by political and technological changes. Nevertheless, as shown in a recent study (Turner 2014), many of the projections made by Meadows et al. (1972) were remarkably accurate.

As can be seen in Figure 1, population, industrial output, food and services per capita, which are relatively straightforward to measure, all follow the predicted curves closely. Resources and pollution are less easy to measure, requiring the use of energy reserves and atmospheric CO_2 as proxies (Turner 2014), and it is these which

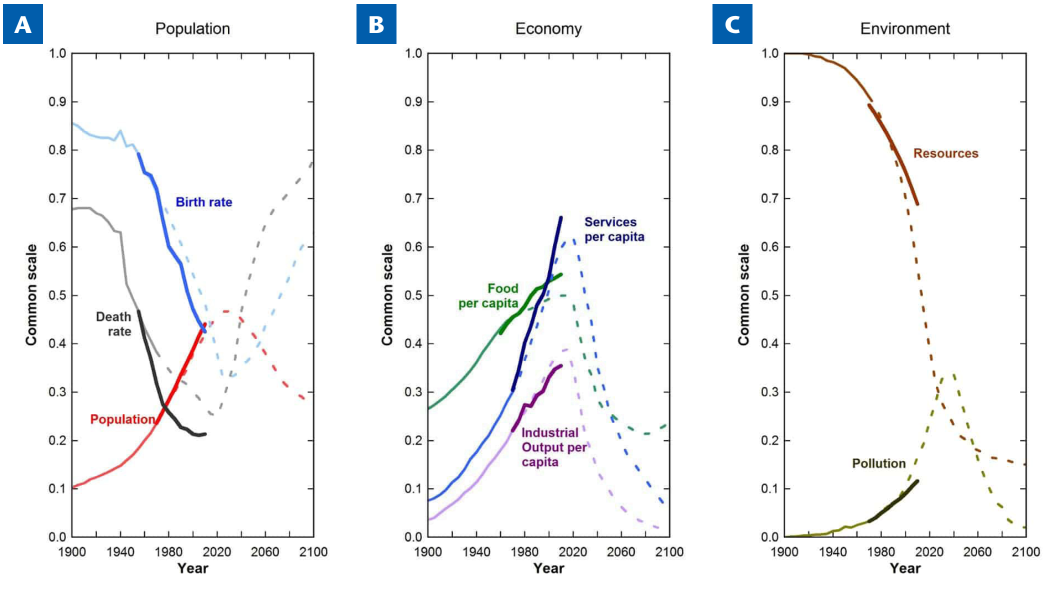

Figure 1 Projections of the standard model in *The Limits to Growth* (dashed lines) compared to pre-1970 data (light solid lines) and updated results (bold solid lines; Turner 2014). Shown are the projections out to 2100 for (**A**) population, (**B**) economy, and (**C**) natural resources. Figures from Turner and Alexander (2014), courtesy of *The Guardian* UK

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THIS ISSUE

"Entire society rests upon—and is dependent upon—our water, our land, our forests, and our minerals. How we use these resources influences our health, security, economy, and well-being." – John F. Kennedy, 35th President of the United States, 23 February 1961

The mining industry is fond of saying, "If it isn't grown, it's mined." And it's true: every material used in modern industrial society is either grown in or derived from Earth's natural mineral resources. What would our lives be like without mining? Imagine a world without bicycles, cars, railroads, cell phones, medical-care items such as X-rays and surgical tools, or even electricity and modern plumbing. We wouldn't have any of these things. Natural resources are the foundation of our lives and lifestyles. And, to maintain these modern levels of comfort, the amount of natural resources required per capita for an industrialized nation can be staggering (e.g. see graphic for the US).

The concept of mineral resource sustainability and development weighs heavily on the mind of the international community, given that our Earth has a fixed quantity of mineral resources needed by an ever-increasing human population (currently ~7.5 billion), all of whom want modern comforts and amenities. Although this issue of *Elements* can't come close to addressing *all* the complexities of mineral resources and sustainable development, the authors have provided articles that introduce us to the origins and economics of mineral resources, the different mining methods required to sustainably extract these resources, plus the different processing techniques needed to refine them. We are also provided with examples of how geochemical research can help solve the complex environmental legacies of mining. And, we are challenged to educate the next generation of geoscientists who will be responsible for finding and developing the resources needed to sustain a nation's standard of living, its domestic national product, and its position in the world.

2017 ANNUAL EDITORIAL TEAM MEETING

On Sunday, 13 August 2017, the *Elements* editorial team held their annual staff meeting in Paris (France). The meeting was an invaluable opportunity for our international team to discuss, face-to-face, editorial matters. We addressed the problems and logistics of handling manuscripts, evaluating proposals, setting the topical lineup for the first half of 2019, and we explored the challenges and opportunities for our magazine in this digital age of the internet, social media, and YouTube. We also met with the *Elements* Executive Committee. The members of this committee represent the 17 participating societies and it is they who oversee the financial aspects of our publication. It was a long but productive day.

One of the most time-intensive discussions for the editorial team involved the evaluation of the 13 thematic proposals submitted for the *Elements* 2019 lineup. This was a challenging task because the team only schedules three to four issues at a time. We evaluated each proposal with respect to the potential interest and relevance of the topic for our diverse readership; we assessed how well the proposed topic would be covered by the suggested articles; and we considered the qualifications and diversity of the proposed authorship. On the basis of these discussions, we accepted the following thematic proposals: "Planet Mercury" (February 2019), "Reactive Transport Modeling" (April 2019), "The South Aegean Volcanic Arc" (June 2019), and "Weathering: A Unifying Process in the Geosciences" (August 2019).

If you missed our last proposal deadline, we invite you to submit your ideas to us by 15 January 2018 when we will finalize the remainder of the 2019 lineup.

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determine the collapse of the system in the standard model. Arguably, however, and despite the global financial crisis in 2007–2008 and its aftermath, there is no evidence yet of system collapse. This tends to confirm the view that the standard model is too pessimistic. It is, however, interesting to consider some of the more "optimistic" scenarios treated in *The Limits to Growth*.

In one scenario, Meadows et al. (1972) assumed unlimited resources and that a low-CO_2–producing energy source replaced fossil fuels. But, this still led to collapse of the system because of pollution. Meadows et al. (1972) then added strict pollution controls with the assumption that pollution per unit of industrial output declines to 25% of its level in 1970. In this new scenario, population and industrial output per person rise well beyond their peak values in the standard model but the system again collapses well before 2100 because capital is diverted from industrial output into food production, and the population declines as food per capita becomes inadequate.

So how do we avoid collapse of the global system? Meadows et al. (1972) explored the parameters required for global sustainability and equilibrium. This required them to set birth rate equal to death rate with globally available birth control, and to limit the growth in industrial output by shifting societal values away from material goods towards education and services. Pollution and resource consumption also needed to be reduced to one-quarter of the 1970 values per unit of industrial output, and capital be diverted to food production, even where it is not financially profitable. Clearly, as seen in Figure 1, there has been little progress towards such a system. One can argue that our current political structures and values are inconsistent with changes in these directions. Nevertheless, *The Limits to Growth* has had enormous political influence, not least here in Europe, and was the stimulus for much of the environmental movement. Don't we all wish that our work could be so widely read and discussed!

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