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VIEWS III

A Path Forward

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(SEG 1983 F)

It has become a truism that we are prospering because we have discovered the benefits of specialization. By applying intellect to manageable pieces of innumerable problems, we are developing insights and technologies at an astounding and accelerating rate. We love and are good at solving problems, and by so doing we create wealth. But this has the interesting ramification that, since only a few specialists understand each solution, everyone else is unsure that the solution is correct. The uninvolved (nearly everyone) fear things may be out of control. Indeed, the human enterprise is completely unmanageable, and in this sense is completely out of control. This makes us anxious.

Resource geology illustrates this situation well: supplying essentially indefinitely a human population that will grow to a peak of 10.5 billion in 2100 (Demeny, 1984) with the energy and minerals required for everyone to enjoy a European standard of living can certainly be done, and done with minimal and ever-diminishing environmental impact. The skills of innumerable problem-solvers will assure this result. But convincing the general public to accept success is perhaps more difficult than convincing them to accept failure. How do we persuade our fellow citizens that the future is bright? How do we engage the next generation to meet the resource challenge?

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The elements of an answer seem to me to be that we must convince our colleagues that the goal of resource supply is important and that the challenges, though hard, can be met, and then we must convey the information needed for the next generation to make contributions that will span 30- to 40-year careers. This last is the most difficult element of the proscription.

Consider the relatively easy parts first. Of course, supplying energy and mineral resources at the current European level to 10.5 billion indefinitely is an important goal. Without this goal, a very large fraction of humanity would rightly perceive they have no future and, even more importantly, they would correctly perceive that they have no stake in a common future. Fighting over who will have and who will not is a future that none could want.

RESOURCES

Is resource supply at the needed levels feasible? Of course it is. Our biomass, as highly as we regard it, will not tax the planet very much. Previous opinions in this series have considered land-based resources and argued, at least implicitly, that they alone can meet the challenge. But it will be much easier if we include the three-fourths of our planet that is covered by oceans. To raise power consumption of everyone today to the European level of ~7 kW per capita would require tripling the world power generation from 15 to 45 TW (IEA, 2008), and when the human population grows to its peak of 10.5 billion 100 years from now, 72 TW will be required. Going from 15 to 72 TW over 100 years is a growth rate of only 1.6 percent, which is not a very daunting challenge provided energy sources are available, and they are.

Although with breeder technology the current reserves of uranium (~35 Mt of U_3O_8) would last a little more than 100 years, the oceans contain 4.6×10^9 t of dissolved uranium that can be recovered today at a cost about twice the current mining cost. The cost of fuel is a minor component of nuclear energy so it is no barrier. The oceans could deliver 72 TW of power for 78 centuries (see Cohen, 1983).

Copper is fundamental to wiring, electricity generation and transmission, transportation, heating, lighting, motors, electronics, building materials, plumbing, and more. In the rich world each person requires a lifetime nest egg of ~200 kg Cu. Over a 100-year period about half the copper in use is lost (Gordon et al., 2006). In the future we might reduce this loss rate considerably, but we would never get to 100 percent because some losses, such as those due to abrasion, dispersion, and the like could never be fully eliminated. To bring everyone to the European standard of living 100 years from now with the current loss rate would require ~3,150 Mt of copper, and thereafter 1,050 Mt per century would be required to maintain humanity at this standard. The current copper resource is ~1,600 Mt (Gordon et al., 2006), but at the base of the ocean sediment layer there should lie 106,000 Mt of copper metal (Cathles, 2010). If half of this is minable, humanity can be maintained at a European standard for 50 centuries. Similarly for zinc, each person in the rich world needs a nest egg of ~200 kg. Because Zn is used for coatings on iron and the like, about 70% of what is put into use is lost over a 100-year period (Gordon et al., 2006).

However, the zinc resource below the ocean sediment layer is five times larger than the copper resource (424,000 Mt Zn; Cathles, 2010), and half of it could bring us to the European standard and maintain us there for 140 centuries. For 10.5 billion humans to share one-quarter of a hybrid electric car would require about 40% of the known land-based lithium resource (W. Tahil, The trouble with Lithium, http://www.meridian-int-res.com/Projects/Lithium_Problem_2.pdf), but only <3% of the lithium dissolved in the world's oceans[a]. To feed 10.5 billion people will require land and fertilizer, but with fertilization agricultural production on current farmland in the developing world can meet the growing demand where it will occur. Current phosphate (perhaps the most vulnerable fertilizer) reserves are adequate for ~100 years, and phosphate resources could last 500 years at the consumption rates that will be needed (Cisse and Mrabet, 2004). The deep ocean contains in solution enough phosphate to supply humanity for 33 centuries[b], and the phosphorous cycle is such that continental shelf sediments must contain a resource vastly larger than this[c].

Steve Scott has pointed out that the oceans represent an exploration frontier with an area equal to two moons plus two Mars, and furthermore, because less sedimentary cover (none for dissolved components) needs to be removed, and because mining equipment can moved from one deposit to another (there are no permanent mine shafts and infrastructure to be left behind), ocean mining should be cost competitive and more environmentally friendly than land-based mining (Scott et al., 2008; S.D. Scott, pers. commun., 2009), especially since the deep ocean is a desert, with the effects of mining more easily mitigated given the sparse life. In addition, ocean resources are more evenly distributed than land resources, and access to them will therefore be more broadly shared.

Of course, the non-polar deserts of the world could deliver solar energy. At 15 W/m^2 (MacKay 2008), about a quarter of their area could deliver 72 TW. Other renewable sources of energy, especially wind, could also contribute, although competition with agricultural land use and visual impairment of inhabited areas would be more of a factor. With energy, ocean water can be desalinated and water need never be a constraining resource.

This brief review is certainly not comprehensive—but, particularly considering that different, more abundant materials can often fulfill the same function and therefore can substitute for an expensive or scarce material (for example, glass fiber or wireless transmission substituting for copper wire)—it is perhaps sufficient to suggest that the earth's resources of energy and critical minerals are more than adequate to support the anticipated human population for a very long time. This is important. The mere perception that this is the case could be very helpful for global harmony and collaboration. All that is required is the belief that resources can be supplied, and the knowledge that there is a workforce capable of the innovation and problem-solving that will be needed.

[a] Li needed for hybrid car fleet for 10.5 billion people = (10.5×10^{9}p)(1/4 car/p)(8 kWh battery/car)(0.3 kg Li/kWh)(1t/1000kg) = 7.5×10^{6}t Li metal. Ocean contains (170×10^{-9} ton Li/ton)(1.4×10^{18} ton seawater) = 2.4×10^{11} tons Li.

[b] 3300 yr = (90,000 Mt P in deep ocean; Paytan and McLaughlin, 2007)/((0.0026 t P/p/yr developed world demand; Natural History Museum, 1998) (10.5 billion people)).

[c] The phosphate cycle requires that over 9×10^6 t P is deposited on the continental shelves each year (Paytan and McLaughlin, 2007). Over a million years enough P will accumulate to supply 10.5 billion for 300,000 yr.

People and problem solving

How do we develop and sustain a workforce in the West to solve our problems? China and India may do it for us, but the West has a lot to contribute and should do its share. We face some challenges:

Not so long ago every major university in North America and Europe boasted at least one economic geologist and many energy (petroleum)-related geoscientists. Now, having an economic geologist is a rarity, and faculty knowledgeable about resource supply is dwindling. Every year there are fewer who can teach and engage in the fieldwork that is required for exploration, or discuss the issues of resource supply in an informed fashion. And every year there are more who can discuss the negative impacts of such supply. Our universities seem to be becoming ever better at seeing the problems associated with resources, but are less inclined and capable of finding solutions to resource supply.

Because resource supply is a postgraduate profession, however, although not desirable, this declining training at the undergraduate and even the graduate level need not be detrimental. In the past, the research labs of companies like Kennecott, Anaconda, and Shell were superb at attracting individuals trained in physics, chemistry, biology, and math who had an interest in, but only a little knowledge of, geology. They introduced them to the issues of resource supply, and planted seeds of interest that could sprout, years later, in articles like this (I gained my resource grounding at Kennecott's research labs in Massachusetts and Utah). Before you say, "God spare us from repeating that mistake," consider how these company laboratories, and those in national as well as state and provincial geological surveys and institutes, the Key Centers in Australia, the oil industry, and the like have interacted with academic researchers to instruct and train students, developed new technologies, and inspired the geologists who now lead our profession. The problem is that these incubators, by and large, have also dwindled over the past several decades, in part because the spread of talent and technologies that is needed to address resource issues has become so broad that it is difficult for traditional institutions to house and sustain what is needed in a satisfactory fashion.

We also have some huge new advantages, and chief among these would be the World Wide Web, search engines like Google, and communication technologies like Skype. It is now easier than ever before to obtain information and to communicate with experts worldwide. In fact, the dramatic broadening of the talent pool that can collaborate to solve problems is another reason that traditional problem-solving institutions are struggling, but this is also a major opportunity. Problems can always be solved more easily if the right people are engaged, and the bigger the pool, the easier it is to engage the right people.

A path forward

How should we operate in this new situation? Of course, I have no better idea than anyone else, but since SEG has given me a podium, let me make a few suggestions. It seems to me that our ace in the hole is that resource supply is so positive, important, and intrinsically interesting that those who love to solve problems can hardly resist being involved. Especially, as we move into the oceans there will be a lot of questions that need to be addressed, and we will learn a lot scientifically. In the past, resource geology has contributed hugely to the technologies and insights needed to understand how the

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planet operates (the gravitometer, airborne magnetic and EM, reflection seismic, GIS, and other studies), and this will continue. Resources reflect the earth processes that really matter. They are indeed, as Jack Oliver stated years ago, the spots and stains, the chemical signal, of plate tectonics. Even pure academics will be interested. Our challenge is to present our problems and the opportunities our data offer clearly enough to engage the worldwide talent pool.

Seeking to balance the discussion by broadening it to better include all economic geologists, those in industry, government, and academia, would be one helpful step. Increasing the number of economic geologists in academia would be another. The debate between supplying resources and preventing the negative consequences of that supply needs to be more balanced and perhaps the two combined. Including mineral economists in the discussion would also help.

A different step that also might be taken is for the SEG to facilitate the electronic warehousing of data and descriptions in a fashion that is searchable on the web. What is a porphyry copper deposit? What does it look like? What needed materials does it supply? What are the environmental impacts of mining it, and how well are they being managed? What are the scientific and practical issues involved that need to be solved? These are perspectives that we all have built up over our professional careers. Our perceptions differ. Some of our perspectives are half-baked, and some have company proprietary aspects.

But might not we all benefit from making PDFs of our important lectures or industry presentations available in a Google-searchable electronic warehouse? Could this be a way to get a notion of the problems that need to be solved disseminated so that colleagues in different areas could become sufficiently interested that they might ask a few questions, come to a topical workshop or on a field trip (which we should continue to sponsor and advertise)? Books and papers are good, but searchable visual material with enough description attached to be comprehensible and some references or pointers might be even better. Such a resource could be diverse and need tell no coherent or "correct" story, although it should be reviewed to be sure it is not demonstrably incorrect. Those who access it could select what they think is relevant. Maybe all we need to do is to bait some hooks (actually a very large number of hooks). A remarkable secret is that many of us resource geologists (and our colleagues in other fields) would work for nothing (and often do) on problems that intrigue us and we think are important. Wikipedia attests to this.

Regardless of how we do it, surely our biggest challenge is simply to get future resource geologists intrigued with solvable problems of interest to us and let them loose. If we do this and convince the public that the future is bright, that we are capable of indefinitely supporting everyone on a planet with a population of 10.5 billion in an environmentally acceptable fashion, then our generation and SEG will have done its job.

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Mass Underground Mining and the Role of the Exploration Geologist

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INTRODUCTION

A growing awareness exists among many mining company executives, particularly in the world's major resources companies, that the future of some sections of the metalliferous mining industry (e.g., copper, in particular) is becoming increasingly tied to large, deeply buried mineral deposits that can only be mined economically by low-cost, mass (or bulk) underground mining techniques and/or very deep open pits. Moreover, many deposits presently being evaluated for mining,

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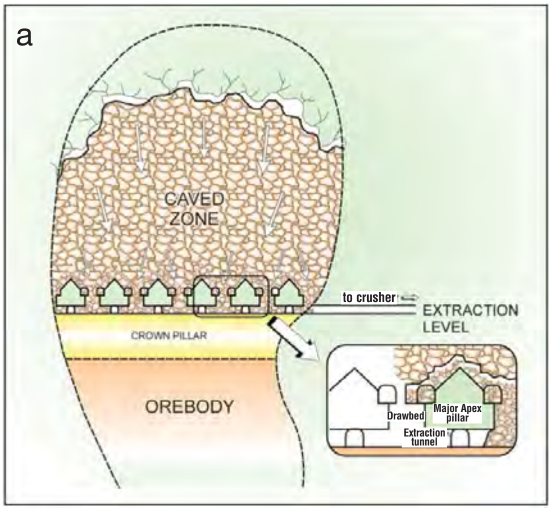

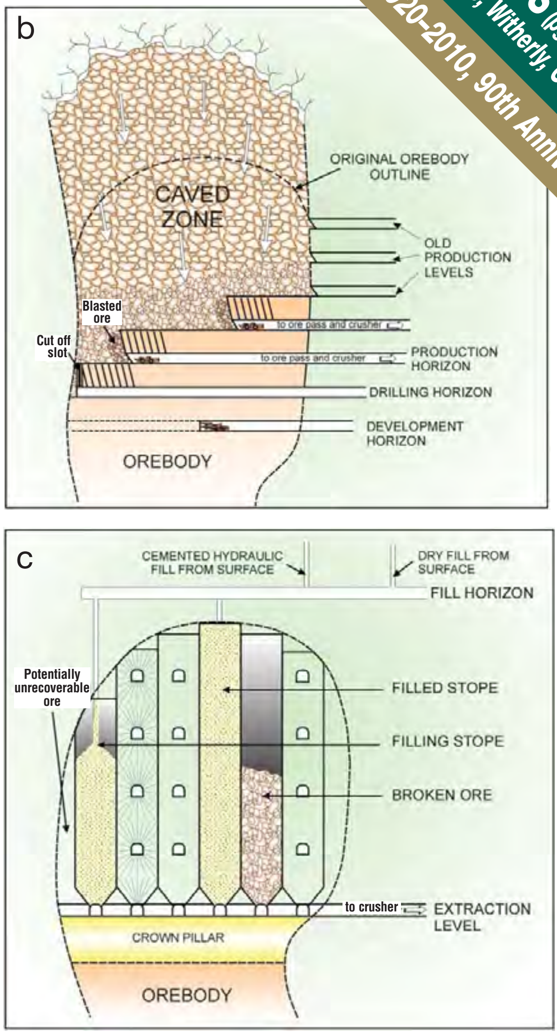

FIGURE 1. Schematic comparison of the essential features of the (a) block-panel caving (BPC), (b) sublevel caving (SLC) and (c) sublevel open stoping (SLOS) methods of underground mass mining (after Logan, 2002 unpub.commun., Newcrest Mining).

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