The Oil Drum: Europe
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Peak Minerals

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This is a guest post from Ugo Bardi and Marco Pagani. Ugo Bardi teaches chemistry at the University of Florence, Italy. He is the president of the Italian section of the Association for the Study of Peak Oil and Gas (ASPO) (www.aspoitalia.net). Marco Pagani is a physicist presently teaching and physics in secondary schools. He is a member of ASPO-Italy, a social and environmental activist, and the blogger of ecoalfabeta. (ecoalfabeta.blogosfere.it)

Abstract: We examined the world production of 57 minerals reported in the database of the United States Geological Survey (USGS). Of these, we found 11 cases where production has clearly peaked and is now declining. Several more may be peaking or be close to peaking. Fitting the production curve with a logistic function we see that, in most cases, the ultimate amount extrapolated from the fitting corresponds well to the amount obtained summing the cumulative production so far and the reserves estimated by the USGS. These results are a clear indication that the Hubbert model is valid for the worldwide production of minerals and not just for regional cases. It strongly supports the concept that "Peak oil" is just one of several cases of worldwide peaking and decline of a depletable resource. Many more mineral resources may peak worldwide and start their decline in the near future.

"Peaking" is commonly observed for oil production in many regions of the world (e.g. Laherrere 2005). According to Hubbert (Hubbert 1956) the production curve of crude oil and of other minerals is "bell shaped" and approximately symmetric; that is the peak occurs when approximately half of the extractable resources have been extracted. From the regional data, it is a logic step to extrapolate to worldwide production and arrive to the conclusion that a global peak ("peak oil") will be reached. In most cases, the analyses based on the Hubbert model say that peak oil could occur within a few years from now. Since crude oil is the single major source of primary energy in the world, it is widely believed that the consequences of peaking could be important, or even disastrous.

However, there is a problem with the idea that we are close to a worldwide oil peaking: no major energy resource (oil, gas, and coal) has peaked globally so far. So, how can we know that the global case is comparable to the regional cases we know? One way to answer this question is to look at the economic and geologic mechanisms that produce peaking. The Hubbert model has been analyzed in several studies (Naill, 1972, Reynolds 1999, Bardi 2005, Holland 2007). In all these models, peaking and decline is the result of the gradual increase of the cost of production of the resource; in turn due to depletion. These costs can be seen in monetary terms, but can be measured in energy units as well. In the case of oil, this increasing cost is related to factors such as the lower success rate with oil prospecting, the necessity of exploiting smaller fields, and the higher costs of processing lower quality oil. These costs will gradually reduce profits and, therefore, reduce the willingness of operators to invest in further extraction. That will slow down the growth and, eventually, cause the peak and the successive decline. This analysis is independent on the kind of resource considered and on the global/regional conditions of extraction.

However, this interpretation is far from being accepted by everybody. Some say that many regional cases of peaking are not due to progressive depletion but to political or market factors or both (see, for instance, Engdhal, 2007 for a recent restatement of this idea). Hubbert's model is also criticized because it doesn't take into account prices. In the global case, it is said, increasing market prices will keep profits coming and, therefore, operators will continue investing on increasing the extraction rate; if not forever at least well beyond the midpoint. This interpretation goes back to the 1930s, (Zimmermann 1933) with the so called "functional model" of minerals extraction that had a considerable success in the later economic literature (e.g. Nordhaus 1992, Simon 1995, Adelman 2004). Recent model studies that take prices into account (Holland 2006) indicate that peaking should occur anyway, but the idea that increasing prices will invalidate the Hubbert model lingers around. Some studies, indeed, assume that oil production will never peak worldwide but, rather, reach a longlasting plateu (CERA 2006).

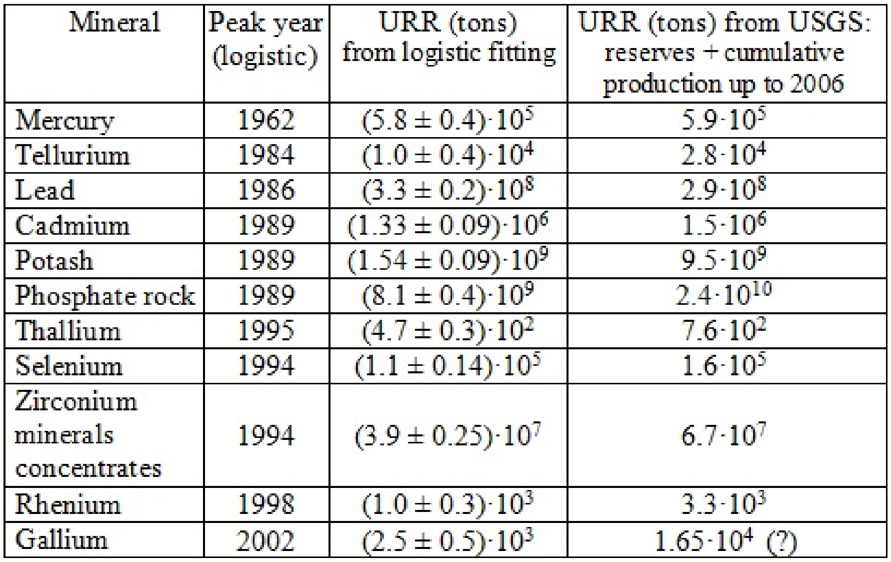
Theories come and go, but one thing is certain: even the most elegant theory needs to be supported by facts. If we can find historical examples of global resources that have peaked and declined following a bell shaped curve, that will strongly support the idea the Hubbert theory holds for global production. Up to last year, there was only one example of such a case reported in the literature: that of whaling in 19th century (Bardi 2006). Whales are not a mineral resource, but the whale stock behaved as a non renewable resource as whales were "extracted" (hunted) at a rate much faster than their reproductive rate. Recently, Dery and Anderson (2007) have shown that the global production of at least one mineral resource, phosphate rock, has peaked in the 1980s.

Just two cases may not be enough to prove the general validity of the Hubbert model but, here, we can report that there are many more cases of global peaking for minerals production. After an exhaustive examination of the USGS database of the world mineral production (Kelly 2006) we found at least 11 cases of minerals that show a global "bell shaped" curve with a clear peak. Peaking was evident by visual examination and it was confirmed by fitting the data using a bell shaped function. We used both gaussian and logistic derivative functions, finding very similar results. Both kinds of curves can be used to fit the Hubbert curve as shown by Bardi (2005) and by Staniford (2006). In addition, we found several more cases of minerals that may have recently peaked or be near peaking, although that is not completely certain yet.

The USGS data were not just examined for the presence of production peaks, but also analyzed in terms of the amount of mineral extracted so far and extrapolated into the future. In its basic form, the Hubbert model states that the production curve is symmetric, that is the production peak occurs when approximately half of the extractable resource has been extracted. The concept of "extractable resource" is ultimately defined by the area under the extraction curve at the end of the cycle; it is extractable what is actually extracted. However, in the initial phases of the extraction cycle, it is possible to estimate this quantity as the "ultimate recoverable resources" (URR). According to BP (2007) in the case of crude oil, the URR is defined as *"an estimate of the total amount of oil that will ever be recovered and produced. It is a subjective estimate in the face of only partial information."* This estimate is even more subjective in the case of minerals other than oil for several reasons. One is that the knowledge of the world resources may be much more uncertain than in the case of oil. Another difficulty may be the lack of reliable historical data. Finally, minerals, unlike oil or gas, often appear as "graded" resources, that is as deposits of different concentration. So, it is difficult to determine a cutoff point of what exactly is extractable and what is not.

Nevertheless, the USGS database reports values for the "reserves" of each mineral considered. The concept of "reserves" is defined by the USGS (2007) as *"That part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative."* Conversely, about the "reserve base" the USGS says that *"The reserve base includes those resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those* *that are currently subeconomic (subeconomic resources).”* Obviously, the reserve base is much larger than the reserves in the USGS estimations. From these data, the URR for each mineral resource can be estimated as the cumulative production up to now plus the remaining extractable amount. The latter can be taken as equal to the reserves or to the reserve base. We tried both possibilities and we found that in all cases the area under the extrapolated bell shaped curve is in much closer to the amount obtained using the “reserves” rather than the reserve base, as we’ll show in the following. Note, anyway, that a discrepancy in this comparison does not, in itself, invalidate the Hubbert model: it may simply indicate that the estimations of reserves are approximate or wrong.

We examined 57 cases of mineral extraction from the USGS data. Of these, we found 11 cases where a clear production peak can be detected. These cases are listed in table 1. The table contains also the URR derived as the sum of the amount of the already extracted resource (up to 2006) and the amount of the reserves listed in the USGS tables. This value can be compared to the amount that the logistic or gaussian fitting of the curve provides.



Mineral	Peak year (logistic)	URR (tons) from logistic fitting	URR (tons) from USGS: reserves + cumulative production up to 2006
Mercury	1962	$(5.8 \pm 0.4)\cdot 10^5$	$5.9\cdot 10^5$
Tellurium	1984	$(1.0 \pm 0.4)\cdot 10^4$	$2.8\cdot 10^4$
Lead	1986	$(3.3 \pm 0.2)\cdot 10^8$	$2.9\cdot 10^8$
Cadmium	1989	$(1.33 \pm 0.09)\cdot 10^6$	$1.5\cdot 10^6$
Potash	1989	$(1.54 \pm 0.09)\cdot 10^9$	$9.5\cdot 10^9$
Phosphate rock	1989	$(8.1 \pm 0.4)\cdot 10^9$	$2.4\cdot 10^{10}$
Thallium	1995	$(4.7 \pm 0.3)\cdot 10^2$	$7.6\cdot 10^2$
Selenium	1994	$(1.1 \pm 0.14)\cdot 10^5$	$1.6\cdot 10^5$
Zirconium minerals concentrates	1994	$(3.9 \pm 0.25)\cdot 10^7$	$6.7\cdot 10^7$
Rhenium	1998	$(1.0 \pm 0.3)\cdot 10^3$	$3.3\cdot 10^3$
Gallium	2002	$(2.5 \pm 0.5)\cdot 10^3$	$1.65\cdot 10^4$ (?)

Table 1

For 4 minerals (Mercury, Lead, Cadmium and Selenium) we find a good agreement of the URR determined from the logistic fitting with the URR determined from the USGS data (cumulative production so far plus reserves). For 5 minerals (Tellurium, Phosphorus, Thallium, Zircon and Rhenium) the URR obtained from fitting is still acceptably close to the USGS data, although smaller. The URR derived from the USGS data are significantly higher only for Gallium and Potash. This discrepancy can be due to the high uncertainty of the data for gallium, and for potash because of market reasons described in the USGS data sheet (USGS 2006). If the “reserve base” is used for the estimation of the URR, for all these minerals the results are always much larger than those derived from the fitting of the experimental data.

We show now some examples of peaking. We start with the earliest global peak that can be found in the USGS tables, that of mercury (Fig. 1).

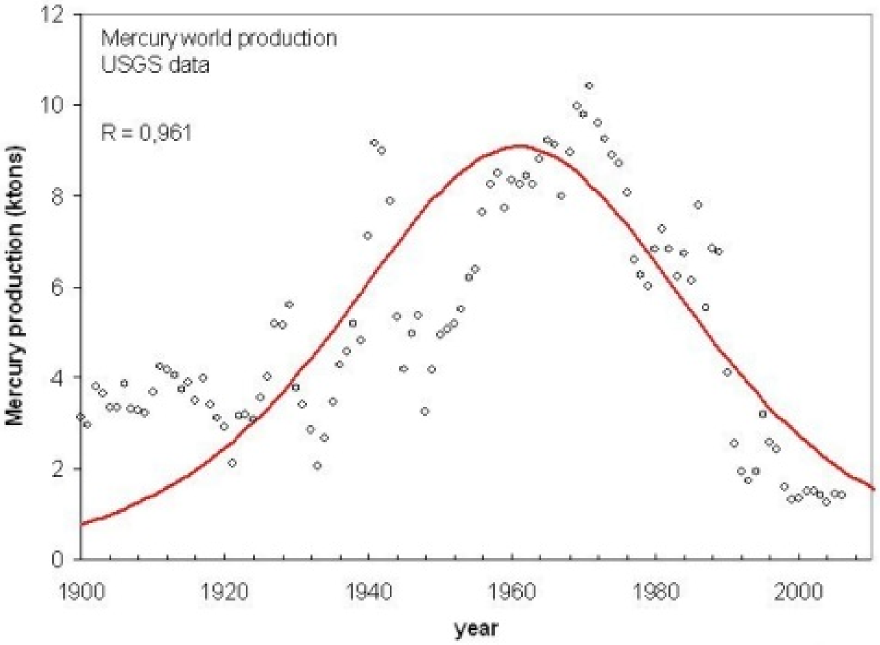


Figure 1, click to enlarge

Here, there is some dispersion in the data, but the fitting is reasonably good and there is no doubt that a global peaking has taken place in the mid 1960s. The total amount of mercury mined from 1900 to the present date is approximately 540,000 tons. According to the USGS data, the world reserves of mercury are reduced today to 46,000 tons which, added to the amount mined so far, provide a total amount of extractable mercury (URR) of approximately 590,000 tons. Considering that some mercury mining took place before 1900, this value is in very good agreement with the value obtained by the logistic fit (580,000 tons).

Another historical peaking is that of lead (fig 2), that peaked in 1986.

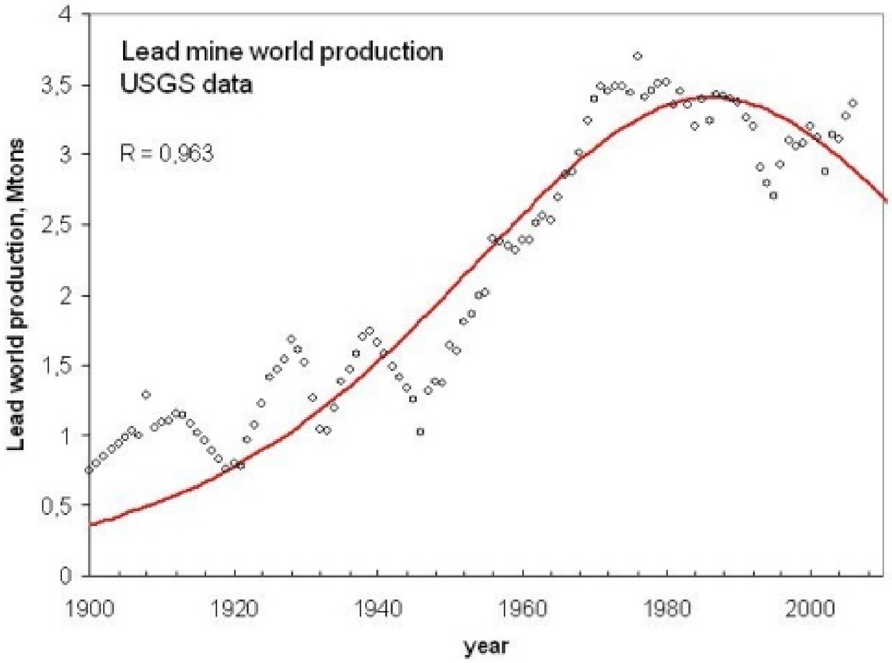


Figure 2, click to enlarge

The fitting is better than in the case of mercury and the data for the URR calculated from the fitting (330 million tons) is in good agreement with the amount calcolated from the USGS data (290 million tons).

A more recent example of peaking is that of zirconium mineral concentrates, (mainly zircon, $ZrSiO_4$), which is the main source of zirconium and zirconium oxide, two important materials, often used as components of high temperature resistant materials (Fig. 3).

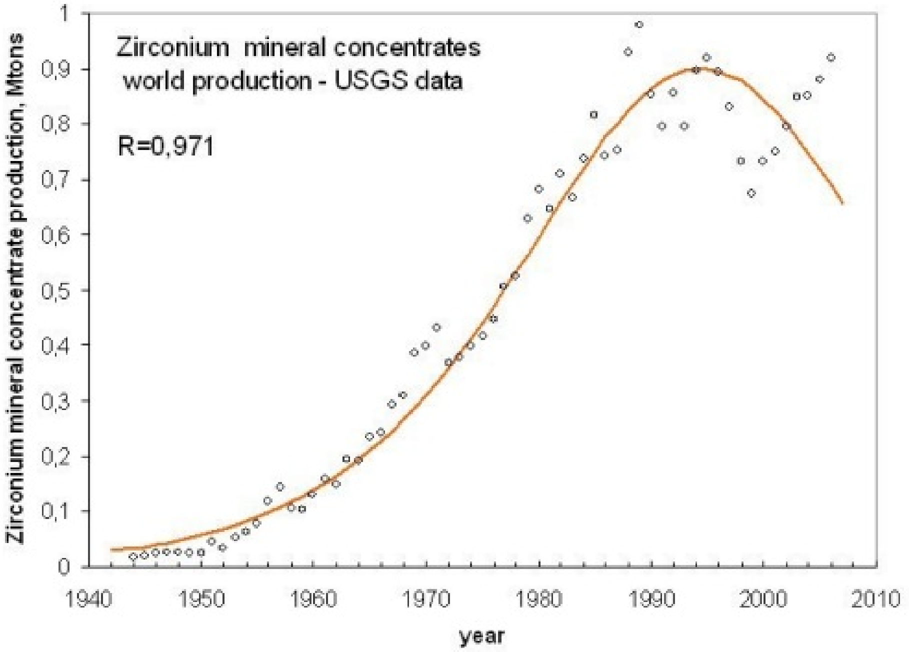


Figure 3, click to enlarge

There is no doubt that the initial nearly exponential growth of production started slowing down in the 1970s and that growth stopped in the 1990 to decline afterwards. The fit of the data gives the date of the peak as 1994. According to the USGS data, the URR for this mineral should be about 670 million tons. The fitting of the production curve produces a smaller value, around 390 million tons. Note that the USGS reserves are reported in terms of tons of ZrO_2, whereas “zirconium mineral concentrates” are a mix of several minerals, mainly zircon ($ZrSiO_4$) and baddeleyte (ZrO_2). A further element of uncertainty, although only a minor one, is the lack of production data for the United States for some years in the USGS data. Taking into account these uncertainties, the agreement can be considered acceptable as an order of magnitude.

Selenium, a metal important for the semiconductor industry, also peaked in 1994 according to a logistic fitting (Fig. 4).

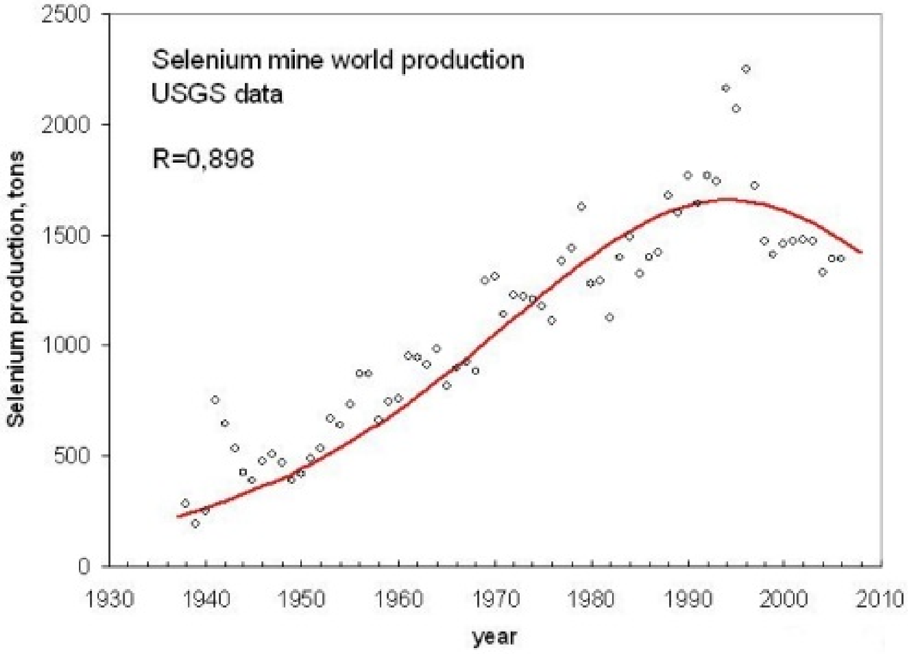


Figure 4, click to enlarge

The Selenium URR calculated from the value of the USGS reserves is in good agreement with the area of the fitting curve.

There is also the case of an even more recent peak; that of gallium. Gallium is another metal important for the semiconductor industry. According to a logistic fit of the data, it peaked in the year 2000 (Fig. 5).

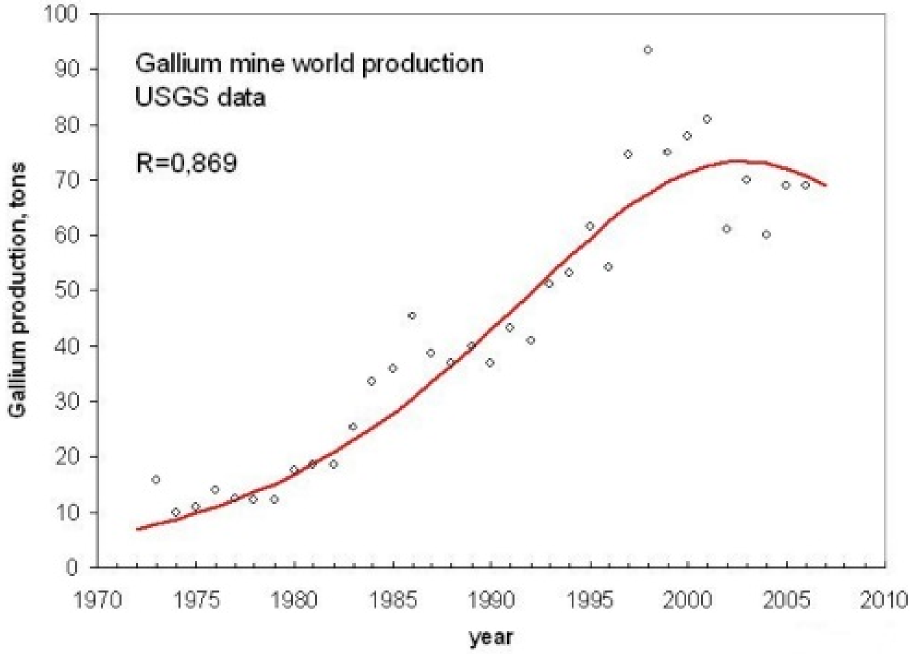


Figure 5, click to enlarge

In this case, the area under the fitting curve is much smaller than that calculated from the USGS reserves data. In this case, the uncertainty in the estimation of the reserves is very high, one reason being that Gallium is produced only as a byproduct of the extraction of other minerals.

In principle, the peaks that we have reported could be interpreted as due to factors other than depletion. Economists tend to distinguish between demand and supply and the decline of production of minerals might be seen as the result of cheaper or safer substitutes entering the market, that is to a reduction of the demand. It would be tempting to attribute the decline in production of mercury to this factor. Mercury is a toxic metal which has been substituted with various other materials and devices and it is now slowly disappearing from the market. But most of the legislation forbidding the use of mercury came much later than the mercury peak (1962) and, as we saw, mercury peaked almost exactly at the “midpoint” of the available reserves, as predicted by the standard Hubbert model. A similar case, reduction in the demand, can be made for the peaking of lead, another poisonous metal. But for many applications, for instance car batteries, no substitute has been found so far for lead. Moreover, also in this case peaking took place almost exactly at midpoint of the estimated resources.

Perhaps the only case were the a decline of production can be attributed to market factors is that of potash (K2O) that peaked at a value of cumulative production considerably lower than midpoint and where market factors were indeed reported as the cause of the decline (USGS 2006). In all the other cases shown in table 1, there is no evident cause that could lead us to think that the decline in production can be attributed to a reduction in demand. For instance, some of the materials listed are important for the semiconductor industry (gallium, tellurium, selenium), others for the metallurgic industry (zirconium, molybdenum), and others for agriculture (phospate rock). No obvious substitutes exist for these materials. Therefore, the peaking and decline of the minerals that we have examined must be interpreted as due, at least in part, to factors related to a reduced supply, in turn related to depletion.

Other minerals examined in the USGS database show a clear slowdown of the rate of increase of production, but it is difficult to prove that a peak has occurred. That depends strongly on the data for the last few years and the data reported by the USGS (Kelly 2006) under the label “Minerals yearbook” arrive only up to 2004. The USGS reports another set of data under the label “Mineral Commodities Summaries”, which are updates for the last two years; available at present up to 2006. Unfortunately, in some cases these sets of data are inconsistent with each other. For instance, Vanadium world production appears to be peaking around 2002 from the “minerals yearbook”, but the data in the “mineral commodities summary” show a sudden jump in production in 2005 and 2006 that brings it well above the earlier peak. The data for vanadium in the successive editions of the “summary” are not consistent with each other, for instance in 2007 the worldwide production for 2005 has been changed to 58,200 tons from the 40,200 tons listed in the tables of the year before. The reasons for this correction are not explained but seem to be related to uncertainties in reporting from countries such as China.

Several minerals in addition to vanadium show similar sudden jumps in production that lead the production curve to abandon the tendency to peaking of a few years before. One such case is that of iron ore (Fig. 6) which shows a true “hockey stick” in the production data.

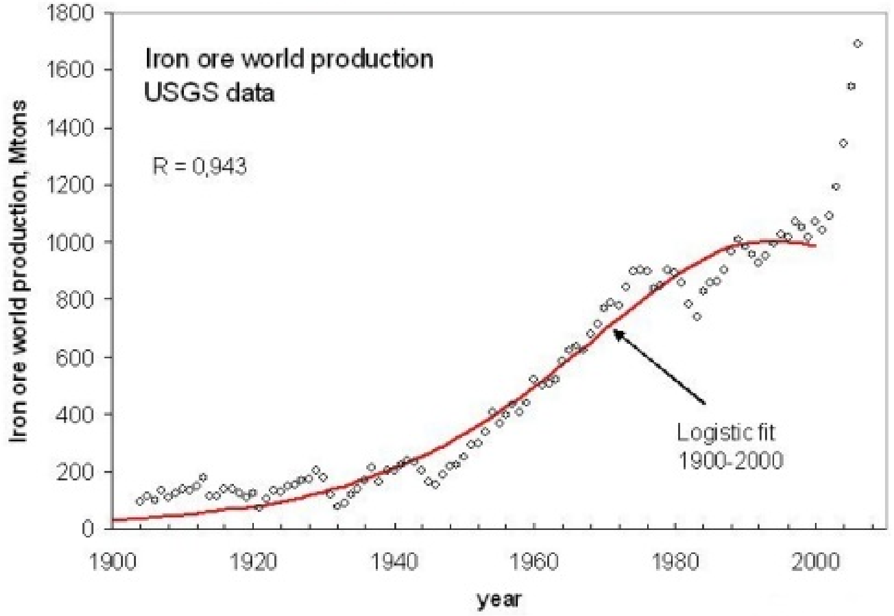


Figure 6, click to enlarge

Here, it is difficult to say whether the rapid rise in the past few years is due to inconsistencies in reporting or to an actual increase of production that may be related to the quickly growing Chinese economy (Pui Kwan Tse, 2005). Probably, both factors are playing a role and the sudden rise in production may be due to the fact that the Chinese economy is, at least in part, “out of sync” with the rest of the world. In any case, we will be able to assess the situation for vanadium, iron ore, and other similar cases only after more data will be available and when their consistency will be assessed by the USGS.

Some minerals in the USGS database show a continuous growth in production that, visually, appears to be nearly exponential. Gordon and coworkers (Gordon 2006) have recently examined five metals that show this behavior: copper, zinc, tin, nickel and platinum. They didn’t use the Hubbert model, but tried to extrapolate the demand for these metals in relation to the expected growth of the world’s population. They reported that *“no immediate concern”* exists for the availability of metal stocks, but that *“the virgin stocks of several metals appear inadequate to sustain the modern “developed world” quality of life for all Earth’s peoples under contemporary technology*.

Taking copper as an example, up to 2006 the experimental data can, indeed, be fitted using an exponential function, but a logistic function provides the same degree of fitting (fig. 7)

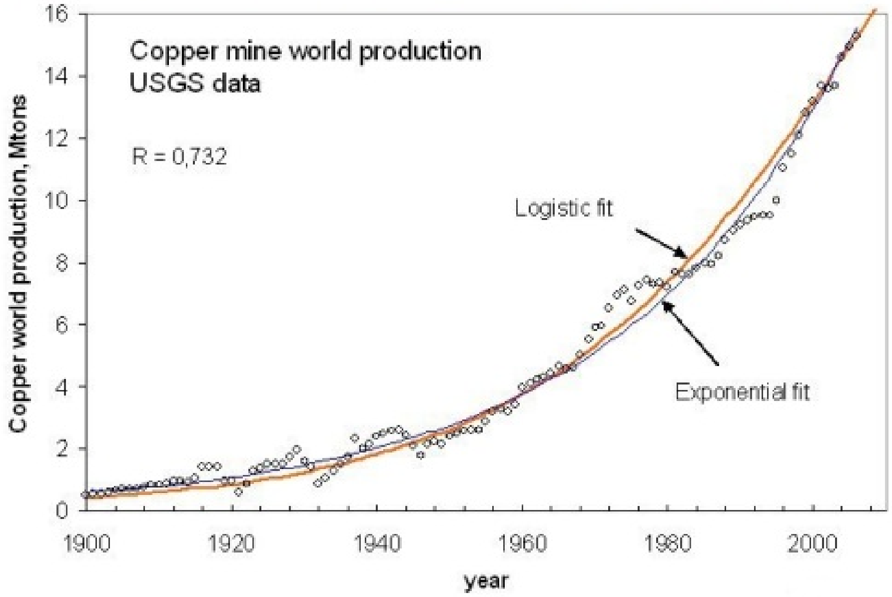


Figure 7, click to enlarge

If we extrapolate the two models a few decades in the future we see the scenarios of Fig. 8, with copper peaking around 2040 according to the logistic fitting.

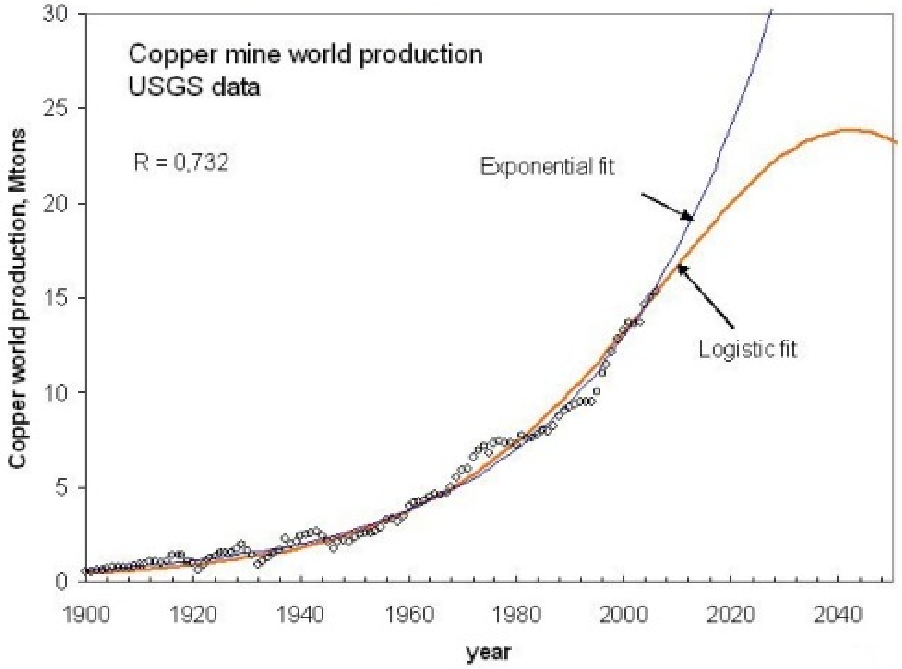


Figure 9, click to enlarge

The results of the fitting are in agreement with the USGS estimation of copper reserves. This amount is about 0,5 - 1 Gtons, even less than the value that can be estimated from the logistic model (2 Gtons). Our analysis is therefore in agreement with that of Gordon, but it provides a more detailed picture of what we may expect in the future. Other metals showing an apparent exponential production growth up to now can be examined in this way. The result is that most minerals should be peaking in the coming decades.

Obviously, all the considerations made so far depend on the assumption that the peaks shown in table 1 are ultimate global peaks. It is a reasonable assumption, but also debatable, especially for those minerals which have peaked most recently. Some minerals are highly sensitive to market cycles and show several peaks. Gold is a case in point: the historical data show a peak in 2001, but the peak may be just one of a series of peaks observed in the history of gold production. Although the minerals reported in table 1 appear to be scarcely sensitive to these cycles, we can be absolutely certain of the "ultimate" peak only after the extraction (or production) cycle has been completed. That, for the time being, is possible at the global level only in the case of whale oil (Bardi 2006) and perhaps of mercury (fig. 1). Nevertheless, the set of experimental data reported here and their analysis provide impressive evidence of the soundness of the Hubbert approach.

We see, therefore, that peaking and decline is a common feature of the worldwide production of most minerals, as the Hubbert model predicts. We cannot exclude that the recent generalized rise in prices of all minerals will start a new wave of investments, but, so far, the predictions of the "functional model" don't seem to be fulfilled.

We need also to consider that the costs of extraction are not just monetary but involve energy costs as well. This fact introduces a further factor that may hasten peaking and decline. The energy involved in the extraction of a mineral commodity, say, copper, does not just depend on the energy needed to extract it from the ore and refine it. It depends also on the energy needed for extracting oil (or coal, or gas, or uranium) and turning it into power and machinery useful for extracting copper. Since fossil fuels are being depleted, more energy is needed for their production and the result is a further increase in the energy needed for the extraction of all minerals. The whole world extractive system is connected in this way. This connection may explain why the peaking of most mineral commodities appears to be clustered in a period that goes from the last decades of the 20th century to the first decades of the 21st century, the period when difficulties in the production of fossil fuels started to be felt worldwide. This connection may also explain why several minerals are peaking for values of the cumulative extraction that are lower than what would be derived from the USGS estimation of the available reserves. Unless new and inexpensive sources of energy become available, we may never able to exploit the abundant "reserve base" of most minerals, and not even the reserves as they are estimated today.

In the end, "Peak oil" seems to be just one of several cases of worldwide peaking and decline of a depletable resource. The bell shaped curve is valid globally and for most minerals, not just for oil and for regional cases. In a few years, it is likely that many more resources will be observed peaking and declining.

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