The Gold peak, easier to model than the oil peak?

Part 1

Natural distributions (size, rank) seem to follow the same fractal pattern (parabolic fractal), when galaxies, earthquakes, urban agglomerations and oil & gas reserves gather the same way (Laherrere 1996).

Mineral discoveries and productions of sedimentary basins also seem to follow the same pattern, displaying several cycles trending towards an ultimate value. Production mimics discovery with a certain time lag, because what is produced needs to be discovered first.

However productions display limitations both above ground and below ground. The main below ground limit is that the energy invested should be less than the energy returned, or EROI (*Energy Return On Investment* should be higher than 1). But EROI is very hard to estimate, except by converting expenditures in energy with assumed ratios.

Hall et al (Energies 2009-2 « *What is the minimum EROI that a sustainable society must have?* ») propose a minimum EROI (over 3?), when the real limit is 1 (except with subsidies!).

For long, I thought that gold production was different from fossil fuels production, because gold exploration has no energy limit, only cost. Gold concentration can vary largely, their contours uncertain and the limit (cutoff) is economical, when crude oil deposits are discrete and the concentration is either almost 100% (forgetting unmovable water) or 0%. However oil supply (to satisfy oil demand) includes much more than crude oil or bitumen with natural gas liquids, refinery gain and other liquids from coal, biomass. Unconventional oil is more limited by the size of the tap than by the size of the tank (resources).

Gold is extracted with mines at about 4000 m when coal reserves are limited at about 1800 m and onshore because of EROI constraints (waiting for a breakthrough on in situ gasification). But looking at the problems in South Africa (which for long was the main producer), it appears now that diminishing grade and too much energy needs will be the limit. The world's main gold mine is gold in the sea and no one is even thinking of it!

As a retired oil and gas explorer (geologist/geophysicist), I am very interested in minerals, but I know very little about gold mining (I did try to pan for gold in Australia) and I have gathered all that I could find on the web, to present the main facts about the main producers.

I found that little reliable historical data exists and the main source of production since 1933 by country seems to be the annual yearbooks from USGS, but unfortunately no correct compilation was made of them, because the past wrong estimates (specially for FSU) were not corrected. China data is not considered as sure as the data from other countries.

However USGS provides good maps of gold mines.

I have to thank Gavin Mudd from Monash University Australia, who has done a terrific work on gold and has written very good papers and who has provided me with historical values for most producing countries.

The site www.goldsheetlinks provides gold production data since 1970 (though the data for Russia gold is wrong for the Soviet period) showing the main producers, which were in 2000 South Africa followed by US then Australia. But in 2008 the main producer is China on the rise when South Africa, US and Australia are at the same level and declining.

Figure 1: annual gold production from main producers from goldsheetlinks



The same with total on log scale Figure 2: annual gold production for main producers in log scale



As shown in the previous graph South Africa was by far the largest producer, but not anymore, it is now China, Australia and US that are producing as much as South Africa!

Let's study the main producers:

-South Africa

Gold occurs in many places in Africa Figure 3: gold map of Africa



Figure 9C. Map showing location of major deposits of silver, gold, mercury, and fluorspar (fluorite).

South Africa production started around 1880 and the cumulative production has reached over 50 kt and can be modelled with two cycles for an ultimate of 58 kt; leaving a yet to produce of 8 kt when USGS estimates the reserves (remaining reserves) at 6 kt and reserve base (resources) at 30 kt. Figure 4: South Africa cumulative gold production & modelling



South Africa annual gold production is compared to gold price and modelled with 4 cycles Figure 5: South Africa annual gold production & modelling



Gold mine grade is a very important element of gold mining economy. The present linear trend of South Africa's gold grade will reach zero around 2060, which makes our annual production forecast look optimistic with the 58 kt ultimate.

Figure 6: South Africa gold grade



South Africa gold grade decline could be sharper because deep mining consumes a lot of energy. US gold decline is sharper.

Gold official « reserves » are in fact what is in the banks, and should not be confused with geological reserves (future production).





-Ghana formerly Gold Coast

Ghana has a long history of mineral production and gold mining has been prominent in the economy of Ghana for about 2000 years using indigenous methods. Historically, this method for gold mining attracted Arab traders into the country and earned Ghana the name Gold Coast. Between the 14th and 19th century, the Gold Coast produced about 14 million ounces of gold using indigenous methods. Modern gold mining in Ghana essentially began with Frenchman Pierre Bonnat, the father of modern gold mining in the Gold Coast. In 1895, Ashanti Goldfields

Corporation began work in the Obuasi district of Ghana, developing the Ashanti and other mines, which have produced the largest proportion of gold since 1900 in the countries of the Gold Coast.

The cumulative gold production reaches 1.7 kt in 2008 and can be modelled for an ultimate of 3.5 to 4.5 kt (USGS remaining reserves being 1.6 kt and reserves base 2.7 kt) Figure 8: Ghana cumulative production & modelling for an ultimate of 3.5 & 4.5 kt



Ghana gold production should peak around 2015 at a level of about 110 t/a Figure 9: Ghana annual production & modelling for an ultimate of 3.5 & 4.5 kt



US are famous for the gold rush of 1849 in California, but gold occurs in other places. Figure 10: US gold map



Figure 23. Map showing the location of the major gold mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Numbered deposits are discussed in the report: 1 – Fort Knox; 2 – Donlin Creek; 3 – Homestake; 4 – Betze/Post; 5 – McCoy/Cove; 6 – Rochester; 7 – McLaughlin; 8 – Round Mountain; and 9 – Mesquite.

Despite some production in Appalachian as early as 1792, US gold cumulative production really started around 1850 and reached 17 kt at end 2007. The ultimate is estimated at 20 kt because USGS reports remaining reserves at 3 kt, with resources at 5 kt. Figure 11: US cumulative gold production & modelling for an ultimate of 20 kt



US gold production has shown several peaks: 1852, 1915, 1940 and last and largest 1998. It seems unlikely that there will be another significant peak Figure 12: US annual gold production for an ultimate of 20 kt



Gold production's drastic decline is confirmed by the decline of gold grade Figure 13: US annual gold grade and linear extrapolation since 1980.



US gold grade was 10 g/t during the 60s, declined to 2 g/t in 1980 and it was in the 1990s just above 1 g/t, which is close to economical threshold.

The extrapolation of grade since 1980 up to 1993 (last value) leads towards a zero grade around now.

The largest production since 1980 was in Nevada: Jon Price Nevada Bureau of mines and geology 2007 "*The world has changed: minerals in the 21st century*" http://www.nbmg.unr.edu/dox/changed_9B22.pdf Figure 14: US annual gold production and Nevada contribution



-Canada

Figure 16: Canada and Latin America gold map



Figure 9c. Location and deposit type of major deposits of antimony, fluorspar (fluorite), gold, and silver.

Canada's gold cumulative production reaches 10 kt in 2008 and can be modelled with an ultimate of 12 kt (USGS reserves = 2 kt & reserve base 4 kt)

Figure 17: Canada cumulative gold production & modelling for an ultimate of 12 kt



Figure 18: Canada annual gold production & modelling for an ultimate of 12 kt



Canada's gold grade from 1955 to 2004 can be extrapolated towards 2035, but only to 2010 using the last 12 years!

Figure 19: Canada gold grade



-Australia

The world largest gold nugget was found in Australia (Victoria) in 1869 weighting 74 kg! Figure 20: Australia gold map from www.ga.gov.au



Australia's gold cumulative production was about 12 kt in 2008 and could be modelled for an ultimate of 17 kt (USGS estimates reserves at 5 kt and reserve base at 6 kt). Figure 21: Australia cumulative gold production & modelling for an ultimate of 17 kt



Australia's gold production has peaked in 1997 and its decline will continue until about 2060 if the ultimate is 17 kt.





But since 1940 Australia's gold grade decline seems to trend towards zero around 2035, meaning that the 17 kt ultimate from USGS is too high! Australia's gold trade is now at 2 g/t. Figure 23: Australia gold grade



-Brazil

The Brazil Gold Rush started in the 1690s, when Bandeirantes discovered large gold deposits in the mountains of Minas Gerais.

Brazil's cumulative gold production is 3.4 kt in 2008 and can be modelled for an ultimate of 4 kt & 5 kt (USGS reserves = 2 kt and reserve base = 2.5 kt)

Figure 24: Brazil cumulative gold production and modelling for an ultimate of 4 kt & 5 kt



Brazil's gold production has peaked in 1990 and will decline until 2050 or 2100 depending on the ultimate.

Figure 25: Brazil annual gold production and modelling for an ultimate of 4 kt & 5 kt



Brazil's gold grade has been declining since 1900 and can be extrapolated towards zero around 2050, which leads to consider the USGS reserve estimate too high and only the 4 kt ultimate being likely.



Figure 26: Brazil gold grade

-Peru

Gold was produced long before the Spanish conquest, but data starts in 1491. Cumulative gold production is 2.3 kt in 2008 and modelled for an ultimate of 4 kt. USGS estimates for reserves were high in 2004 but dropped to 1.2 kt with a reserve base at 2.3 kt.



Figure 27: Peru cumulative gold production & modelling for an ultimate of 4 kt

Peru's gold production has peaked in 2005 and will decline until 2020. Figure 28: Peru annual gold production & modelling for an ultimate of 4 kt



-Mexico

Historical gold production is hard to get before 1970 and cumulative production since then reaches 0.6 kt in 2008. USGS estimates reserve at 1.4 kt and reserve base at 3.4 kt.

Figure 29: Mexico cumulative gold production & modelling for a remaining ultimate of 1.5 & 3 kt



Mexico's gold production should peak around 2020, at around 100 t/a! Figure 30: Mexico annual gold production & modelling for a remaining ultimate of 1.5 & 3 kt



-Chile

Like Mexico, Chile's gold production before 1970 is hard to get, since cumulative production is 1 kt and can be modelled with a remaining ultimate of 2 & 3 kt (USGS reserve at 2 kt and reserve base at 3.4 kt)

Figure 31: Chile cumulative gold production & modelling for a remaining ultimate of 2 & 3 kt



Chile's gold production should peak around 2025 at around 70 t/a Figure 32: Chile annual gold production & modelling for a remaining ultimate of 2 & 3 kt



-Russia

Russia's gold industry started in 1745 around Ekaterinburg and in Siberia in 1823 (Korolenko 2004). Russia's data was confidential during the Soviet period and CIA (then USGS) reports were completely wrong. The most reliable source is the recent paper by Russian gold producer NBL CEO M. Leskov *«Winning gold in Russia»* International Mining May 2009

Figure 33: Russia gold map from NBL International



Leskov was giving completely different data from the past CIA reports, but the following graph is hardly readable to keep data still confidential!

Figure 34: Russia annual gold production from Leskov, head of NBL



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Comparing Leskov data (if correctly read) to previous sources shows that discrepancies were huge (more than double)!

Figure 35: Russia annual gold production from different sources



Different sources are:

-USGS minerals yearbooks

In the 1963 report, USSR production is more than 10 Moz since 1950 Figure 36: annual gold production from USGS minerals yearbook 1963 566



FIGURE 3 .--- World production of gold, 1905-63.

In the 1964 report, USSR production is less than 5 Moz 1942-1963 in a new graph for the past, but most researchers kept the previously reported annual data, which was not corrected Figure 37: annual gold production from USGS minerals yearbook 1964



Figure 38: annual gold production from USGS minerals yearbook 1980



Figure 6.-Gold: World mine production.

-Robert G. Jensen, Theodore Shabad, Arthur W. Wright 1983 «Soviet natural resources in the world economy»

 $http://books.google.fr/books?id=GiOU4EGyt_0C\&lpg=PA587\&ots=UPwJNN17rQ\&dq=\%22gold\%20cumulative\%20production\%22\&pg=PA587\#v=onepage&q=\&f=false$

-Jon Price 2007 "The world has changed: minerals in the 21st century" Nevada Bureau of mines and geology http://www.nbmg.unr.edu/dox/changed_9B22.pdf

Figure 39: percentage of annual gold production by country from Price showing an incorrect collapse of Russia production in 1961



-Thomas Chaize and his site http://www.dani2989.com/gold/goldprod0509gb.htm

-V. Korolenko 2004 «Prospects for the Production and Processing of Gold in Russia » -R. Flynn «Estimating Soviet gold production» 1975

Compiling and correcting all the data, the cumulative gold production is at 15 kt in 2008 and is modelled with an ultimate of 20 kt (USGS 2009 reserves = 5 kt and reserve base 7 kt) Figure 40: Russia cumulative gold production & modelling for an ultimate of 20 kt



Russia's gold production should peak again around 2015 at 200 t/a and decline until 2060. Figure 41: Russia annual gold production & modelling for an ultimate of 20 kt



-Uzbekistan

As for all USSR countries, gold data is unreliable before 1991. Uzbekistan's gold production is reported to have started in 1970, but with no data from 1980 to 1991. Cumulative production is at 2.5 kt in 2008 and modelled for an ultimate of 4.3 kt (USGS reserves at 1.7 kt & reserve base at 1.9 kt).

Figure 42: Uzbekistan cumulative gold production & modelling for an ultimate of 4.3 kt



Uzbekistan's gold production has peaked in 1998 and could display a lower peak in 2012 with a decline until 2050:



Figure 43: Uzbekistan annual gold production & modelling for an ultimate of 4.3 kt

-China

There are many gold deposits in China Figure 44: China gold deposits map from USGS 2005-1294



Figure 4A - Main nonfuel mineral deposits in the Asia and Pacific Region. The deposits are tabulated on table 2.

China's gold production was low from 1930 to 1970, but unknown before, gold discovery has been known since 1091 B.C. when little squares of gold were legalized in China as a form of money. http://www.nma.org/pdf/gold_history.pdf

USGS estimates China remaining reserves at 1,2 kt with resources at 4 kt when cumulative production at end 2008 is 5 kt. China's gold ultimate should be 8 to 10 kt.

Figure 45: China cumulative gold production & modelling for an ultimate of 8 & 10 kt



China's annual gold production should peak between 2010 and 2015 and then decline sharply. Figure 46: China annual gold production & modelling for an ultimate of 8 & 10 kt



-Indonesia

Indonesia's gold production is unknown before 1970 and cumulative production is about 2 kt at end 2008 and UGSGS estimates remaining reserves at 3 kt (but 1.8 kt in 2006) with resources at 6 kt (2.8 kt in 2006).

Figure 47: Indonesia cumulative gold production & modelling for a remaining ultimate of 3 & 4 kt



Assuming a cumulative production of 2 kt in 2008 the ultimate is estimated at 5 to 6 kt. Indonesia's annual gold production has peaked in 2005 and should peak again at the same level around 2015-2020 and decline until 2050:

Figure 48: Indonesia annual gold production & modelling for an ultimate of 5 & 6 kt



-Papua New Guinea PNG

PNG's cumulative gold production is at 1.6 kt in 2008 and is modelled for an ultimate of 3 & 4 kt (USGS reserves at 1.3 kt and reserve base at 2.3 kt)

Papua New Guinea gold cumulative production & modeling for an ultimate of 3 & 4 kt 4 3,5 -U=4 kt U=3 ktproduction goldsheetlinks gold cumulative production kt 3 USGS reserves USGS reserve base 2,5 2 1,5 1 0,5 0 1970 1980 1990 2000 2010 2020 2030 2040 2050 2060 year Jean Laherrere 2009

Figure 49: PNG cumulative gold production & modelling for an ultimate of 3 & 4 kt

PNG's annual gold production should peak during the 2010s and decline until 2050. Figure 50: PNG annual gold production & modelling for an ultimate of 3 & 4 kt

