The Oil Drum: Europe
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Peak Gold, Easier to Model than Peak Oil? - Part I

Posted by Luis de Sousa on November 25, 2009 - 10:25am in The Oil Drum: Europe
Topic: Geology/Exploration
Tags: gold, jean laherrère, mineral depletion, peak minerals [list all tags]

This is a guest post by Jean Laherrère on gold. Although of little relevance to our economies in the present day, this precious metal has been used as money for many thousands of years, and still retains its importance and value. In a two part article, Jean analyses how gold mining is subject to depletion.

In this first installment, an assessment of reserves and a production model is presented for each of major gold-producing countries in the world.

Note: This post contains close to 50 images amounting to **2 Mbytes** of data.

Preface
by Ugo Bardi

The question regarding the reasons for the "bell shaped" Hubbert Curve has been around for a long time. Is the curve something that is only associated with crude oil? Does it hold for all fossil fuels? Or is it characteristic of all non-renewable resources? With time, evidence has accumulated that the Hubbert Curve is a very general phenomenon that occurs for all cases where a resource is exploited in conditions of free or nearly free market. The curve is observed also for renewable resources, when the rate of production is much faster than the replacement rate. It is, however, a typical characteristic of non-renewable mineral resources.

In the case of energy resources, the Hubbert Curve is directly related to EROI or EROEI (energy return of energy invested). Declining values of the EREOI reduce the producers' profit and, eventually, lead to a reduction in investments on exploration and development. In the more general case of mineral resources, the curve is still related to energy but, in this case, to the increasing need of energy for exploiting progressively lower grade ores. The case of gold is especially interesting since it deals with a resource whose extraction rate would be expected to be dominated by market prices rather than energy constraints. Indeed, the historical gold production curve is best interpreted in terms of multiple production cycles, each one following a Hubbert Curve. Nevertheless, it is still possible to interpret the curve in terms of an overall Hubbert behaviour which, therefore, appears to be a nearly universal phenomenon in resource exploitation.

Introduction

Natural distributions (size versus rank) seem to follow the same fractal pattern (parabolic fractal) with galaxies, earthquakes, urban agglomerations and oil and gas reserves gathering in the same way (Laherrere 1996).

Mineral discoveries and production in 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, production is limited both by above-ground and below-ground factors. 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 for energy using 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 fuel production, because gold exploration has no energy limit, only cost. Gold concentration can vary largely. The contours are uncertain and the limit (cutoff) is an economic cutoff, whereas crude oil deposits are discrete and the concentration is either almost 100% (forgetting water produced with the oil) or 0%. However, oil supply (to satisfy oil demand) includes much more than crude oil or bitumen: natural gas liquids, refinery gains and other liquids from coal or biomass. Unconventional oil is more limited by the size of the tap (speed of extraction) than by the size of the tank (amount of resources).

Gold is extracted in mines at about 4000 meters deep, while coal reserves for instance are limited to about 1800 meters deep 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 high energy needs will set the limit. The world's main gold mine is gold in the sea and no one is even thinking of that!

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.) I have gathered all that I could find on the web, to present the main facts about the main producing countries.

I found that little reliable historical data exists. The main source of production information since 1933, on a country-by-country basis, seems to be the annual yearbooks of the USGS. Unfortunately, some of the amounts shown are not correct even in more recent editions, because past wrong estimates (especially for the FSU) were not corrected. Data for China is not considered as certain as the data from other countries. However, the USGS provides good maps of the country's gold mines.

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

The site GoldSheetLinks provides gold production data since 1970 (though the data for Russia is wrong for the Soviet period) showing the main producers, which were in 2000 South Africa followed by US, and Australia in third place. But by 2008, the main producer was China with rising production, while South Africa, US and Australia are at the same level or declining.

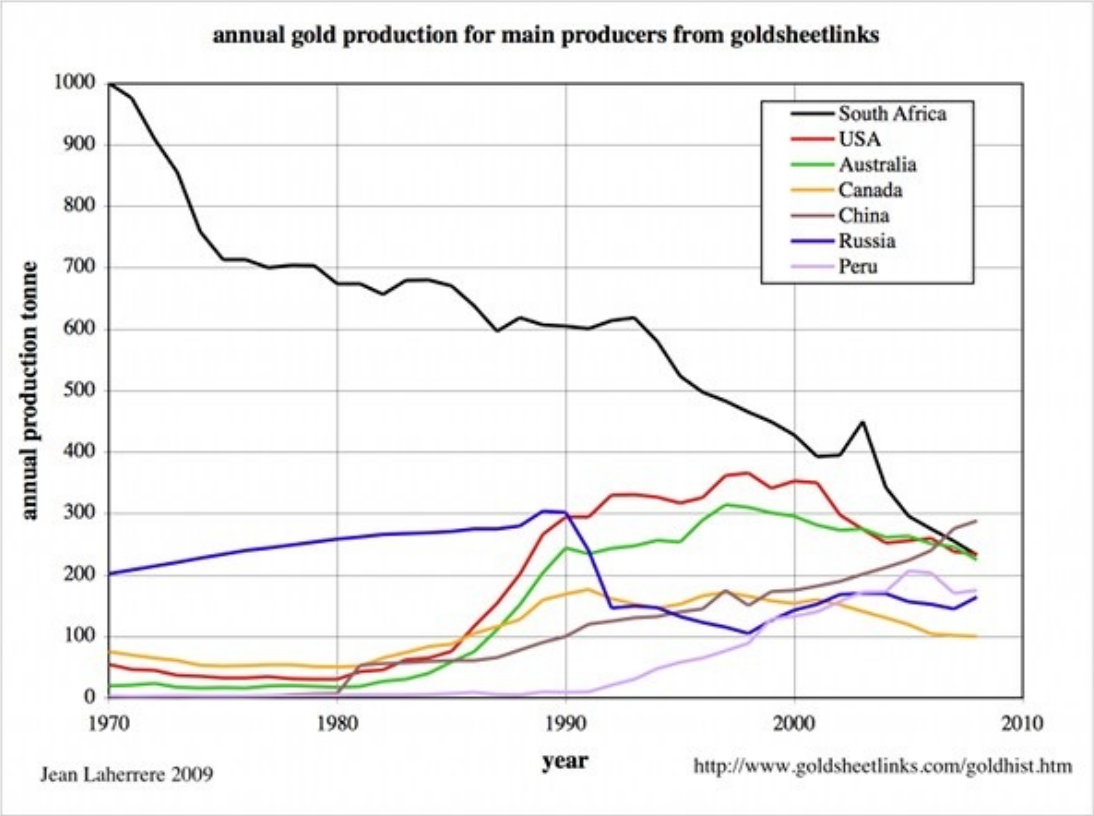


Figure 1: Annual gold production from main producers from goldsheetlinks.

The same with the total on a log scale:

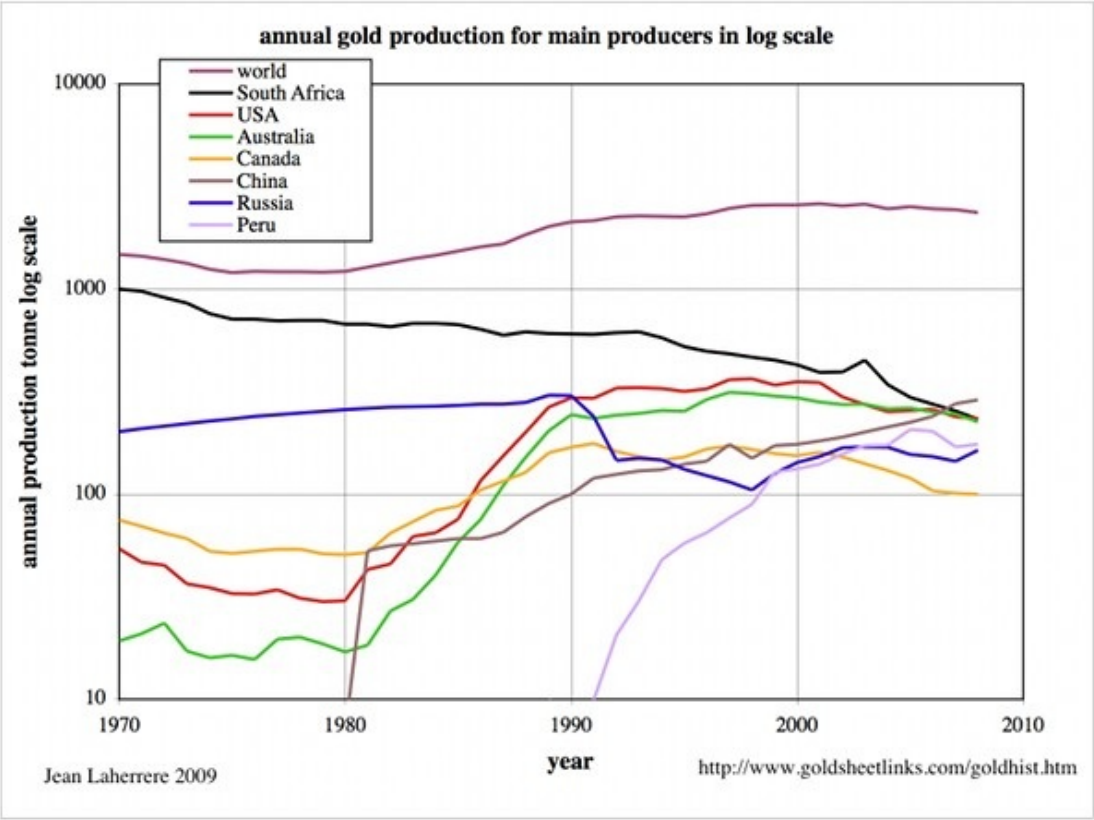


Figure 2: Annual gold production for main producers using a log scale.

As shown in the previous graph, South Africa was by far the largest producer, but it is not any more. First place was taken over by China, with Australia and the US producing as much as South Africa!

Let's study the main producers:

South Africa

Gold occurs in many places in Africa:

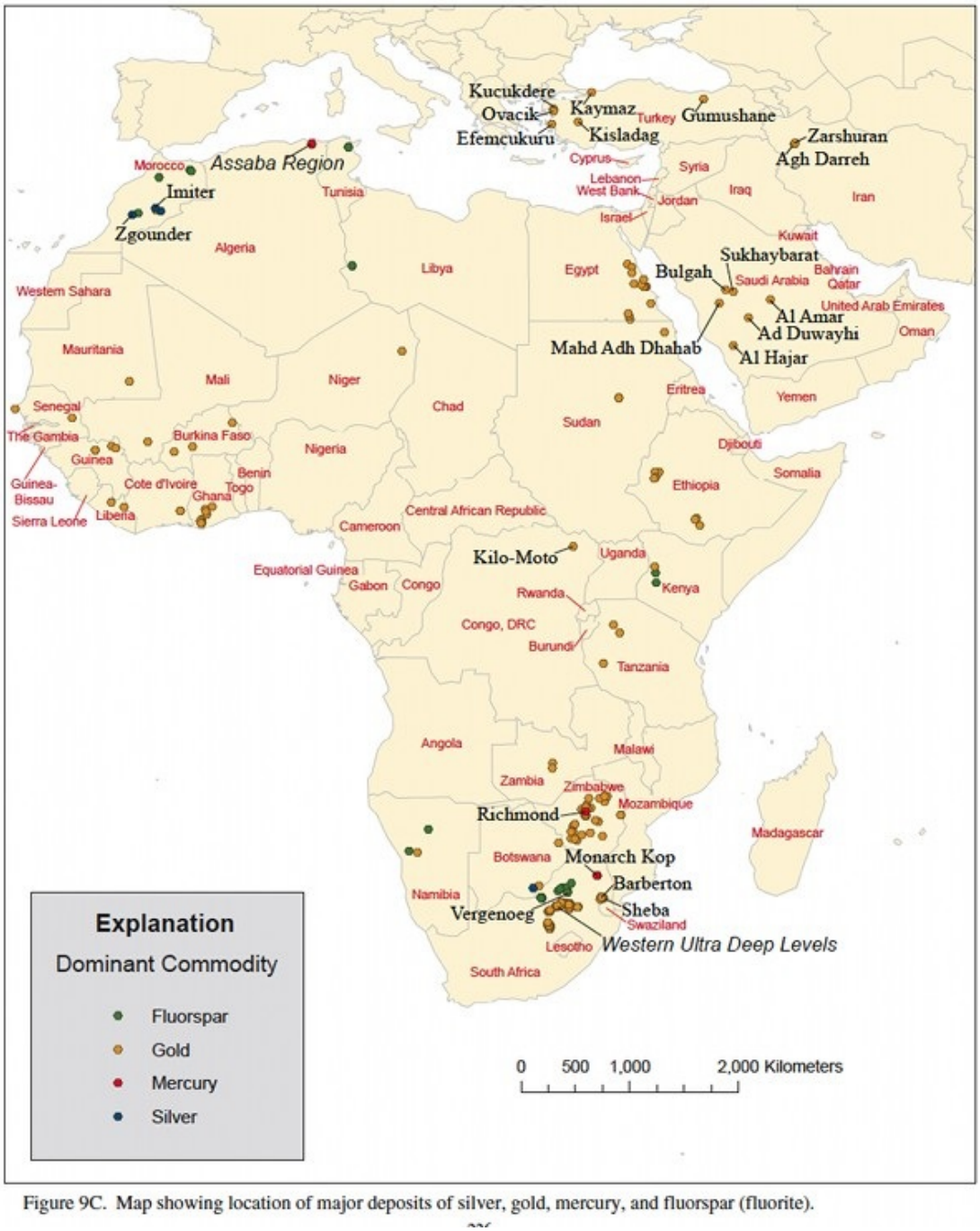


Figure 9C. Map showing location of major deposits of silver, gold, mercury, and fluorspar (fluorite).

Figure 3: Gold map of Africa

Gold mining in South Africa started around 1880, and the cumulative production has reached

over 50 kt. It can be modelled with two cycles for an ultimate of 58 kt; leaving a yet to be produced figure of 8 kt, whereas USGS estimates the reserves (remaining reserves) at 6 kt and the reserve base (resources) at 30 kt.

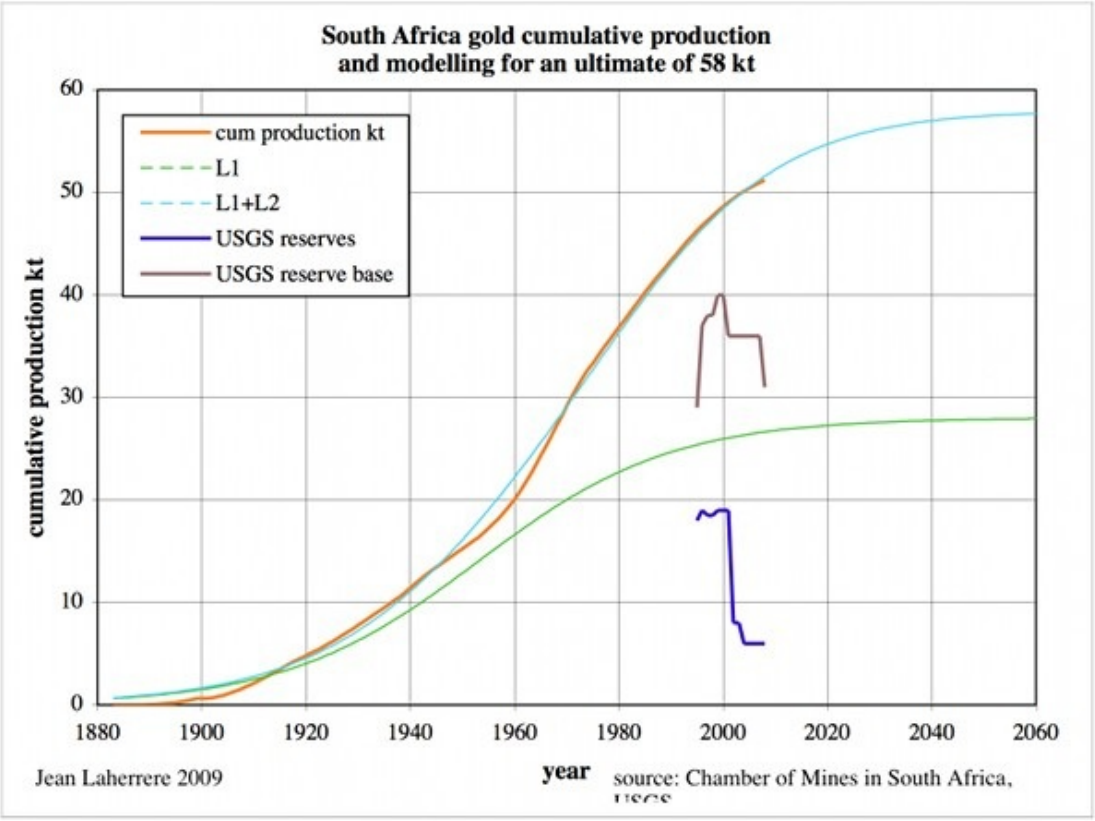


Figure 4: South Africa cumulative gold production & modelling.

Annual gold production from South Africa is compared to the gold price and modelled with 4 cycles:

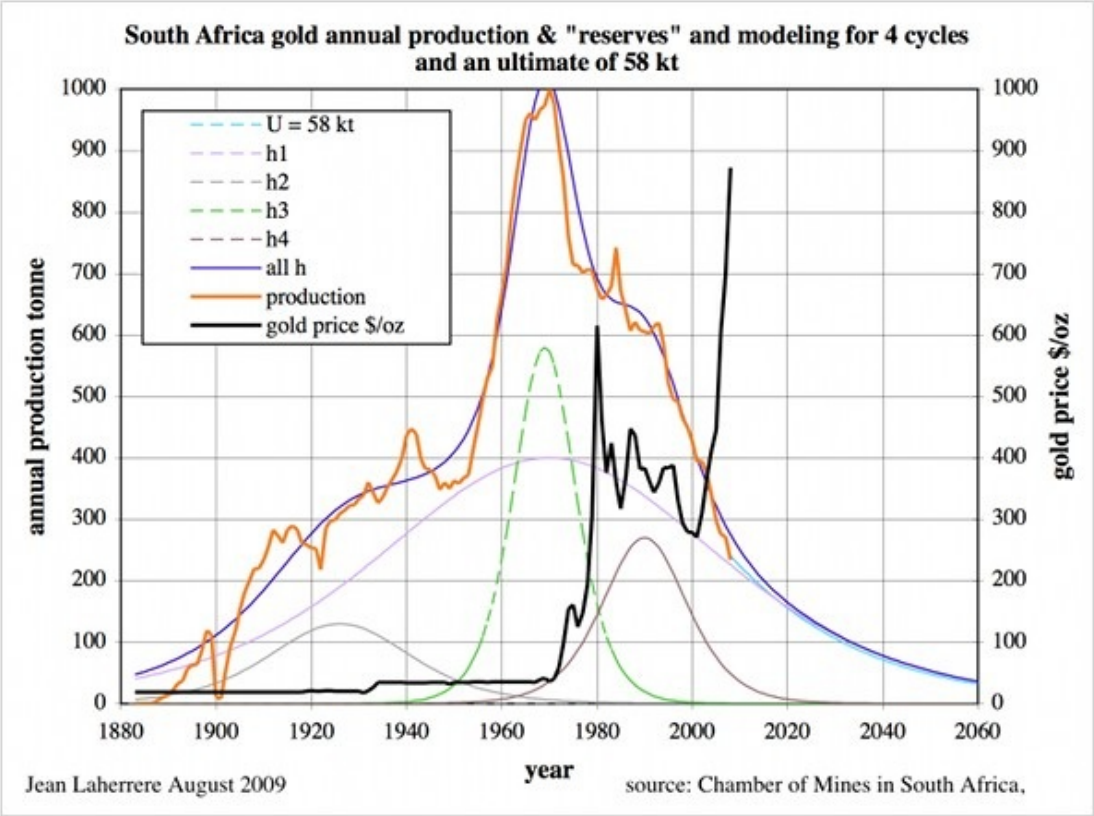


Figure 5: South Africa annual gold production & modelling.

Gold mine grade is a very important element of the economics of gold mining. 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.

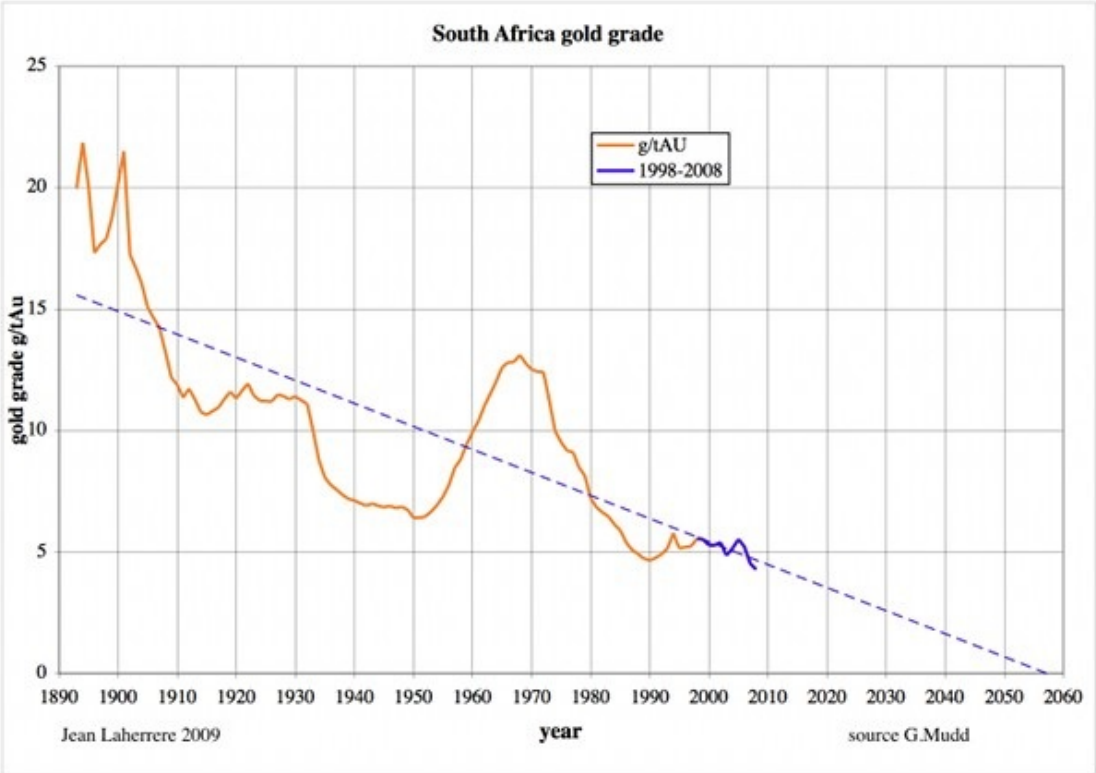


Figure 6: South Africa gold grade.

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

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

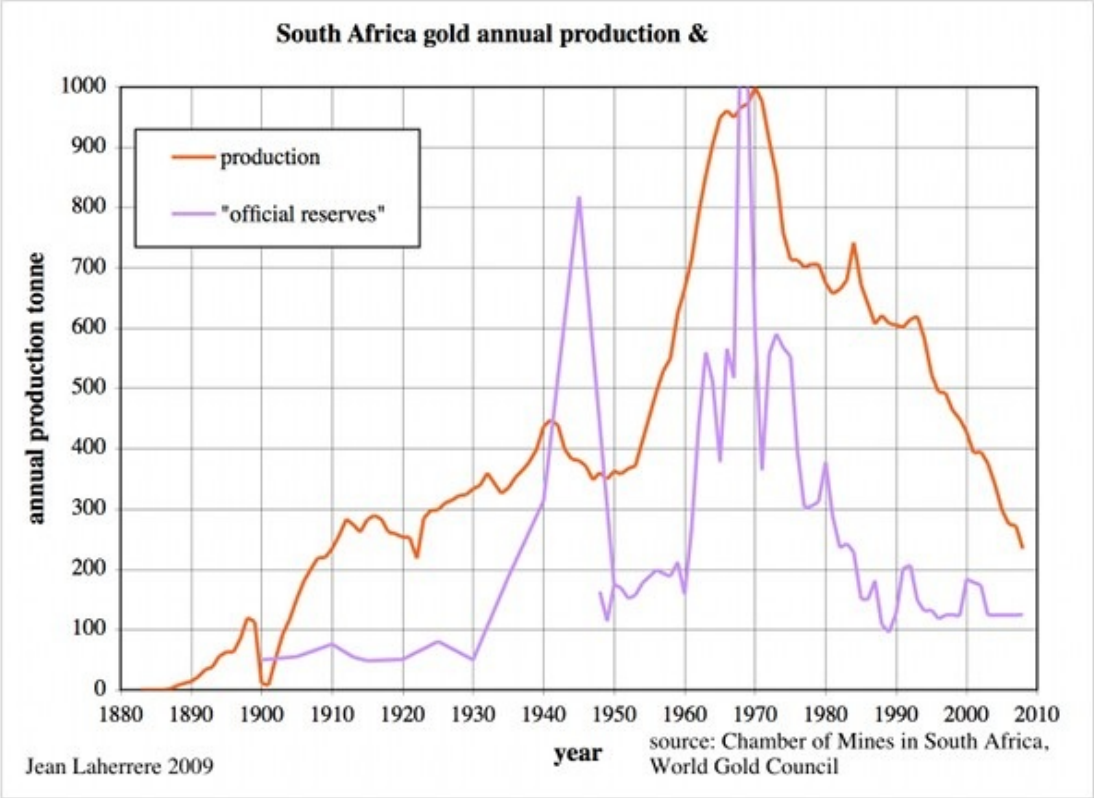


Figure 7: South Africa annual gold production and official «reserves» (in the banks)

Ghana (formerly Gold Coast)

Ghana has a long history of mineral production, and gold mining has been prominent in the economy of Ghana during the last 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 on the Gold Coast. In 1895, Ashanti Goldfields Corporation began working 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 reached 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 reserve base 2.7 kt).

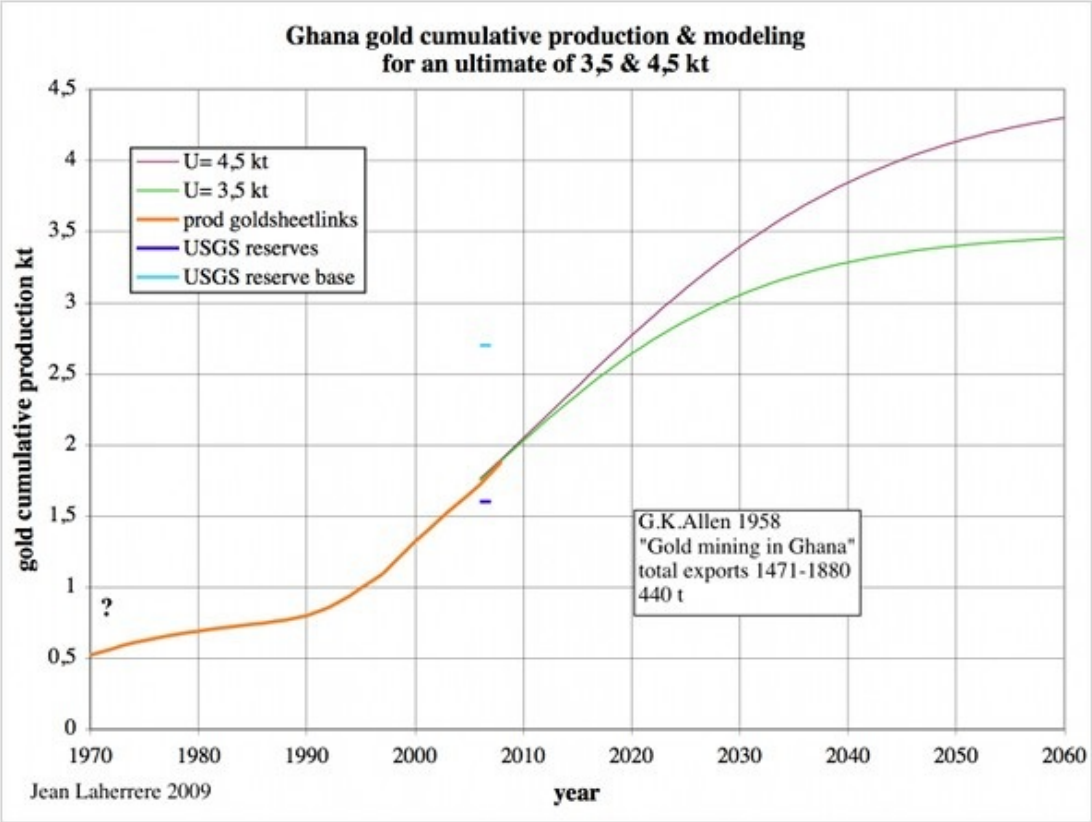


Figure 8: Ghana cumulative production & modelling for an ultimate of 3.5 & 4.5 kt

Ghana's gold production should peak around 2015 at a level about 110 t/a.

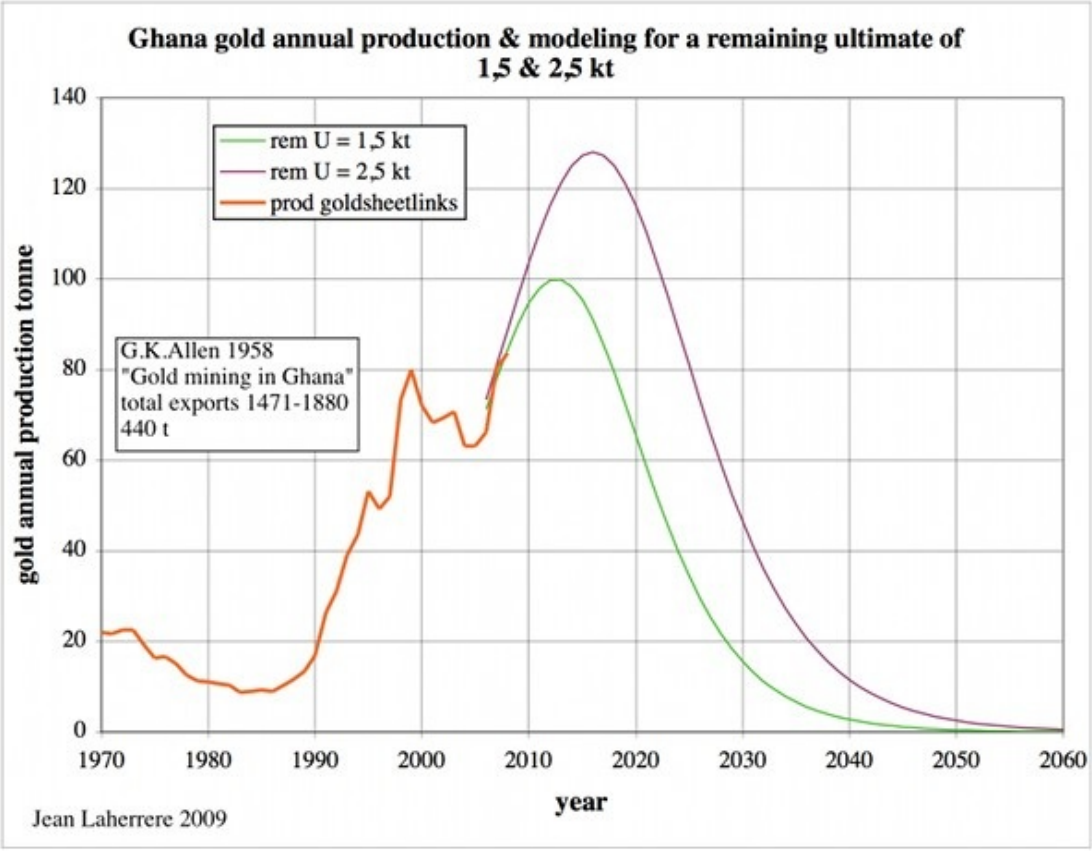


Figure 9: Ghana annual production & modelling for an ultimate of 3.5 & 4.5 kt.

US

The US are famous for the gold rush of 1849 in California, but gold occurs in other places too.

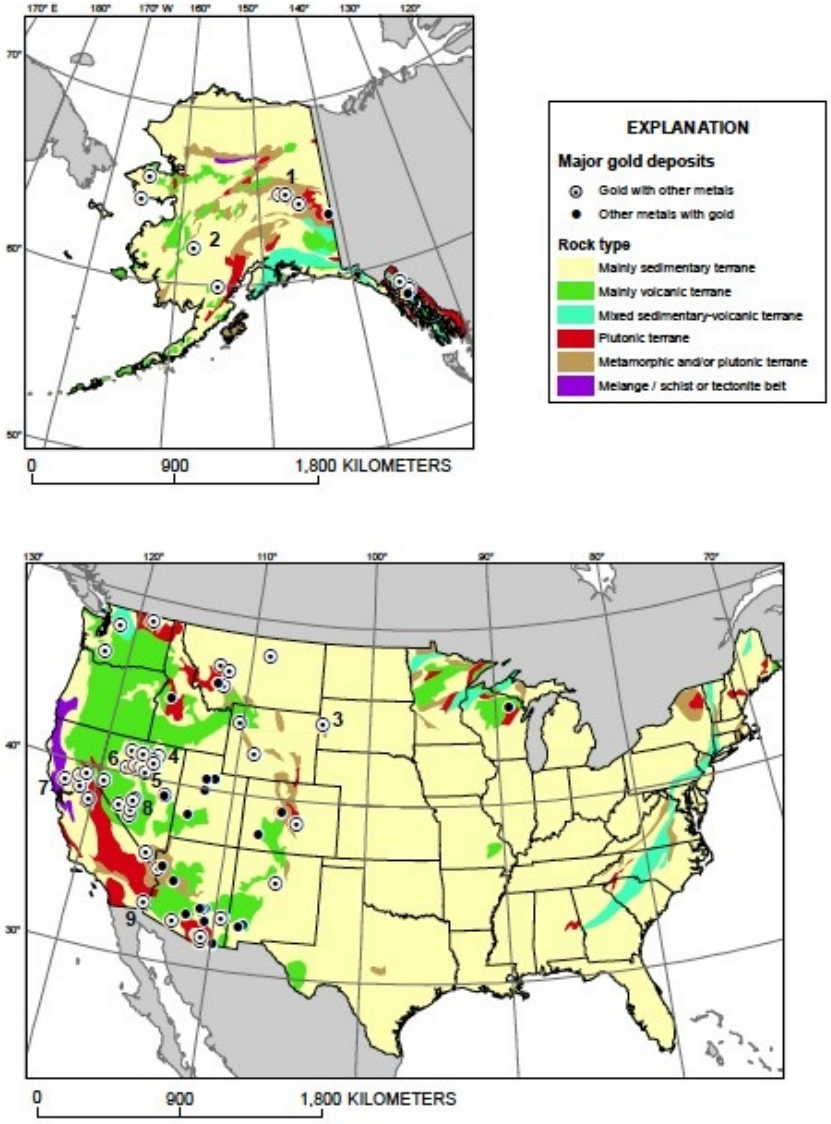


Figure 23. Map showing the location of the major gold mineral deposits of United States listed in appendix 1. Geologic base is derived from Geological Survey of Canada (1995). Numbered deposits are discussed in the report: 1 – Fort Knox; 2 – Donlin Creek; 3 – Homestake; 4 – Betze/Post; 5 – McCoy/Cove;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

Figure 10: US gold map.

Despite some production in the Appalachia as early as 1792, US gold cumulative production did not really take off until around 1850, and reached 17 kt at the end of 2007. The ultimate is estimated at 20 kt because the USGS reports remaining reserves at 3 kt, with resources at 5 kt.

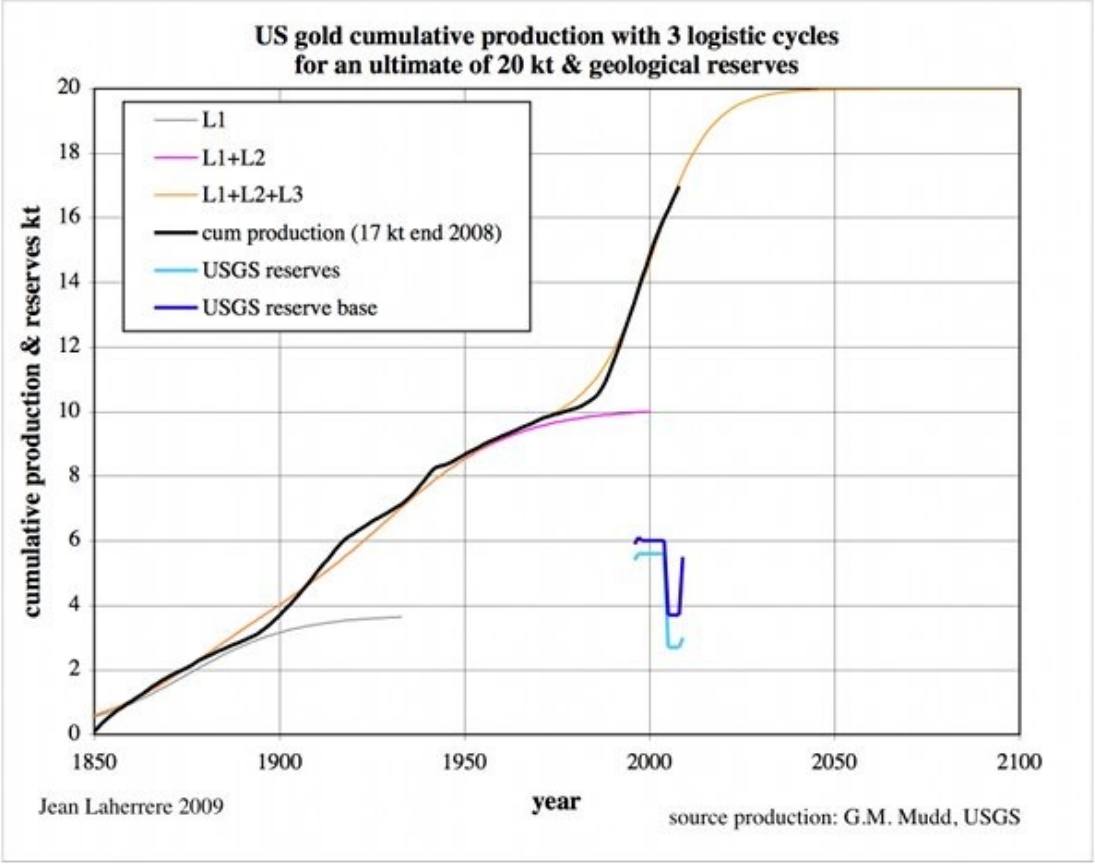


Figure 11: US cumulative gold production and modelling for an ultimate of 20 kt.

US gold production has shown several peaks: 1852, 1915, 1940 and the last and largest in 1998. It seems unlikely that there will be another significant peak.

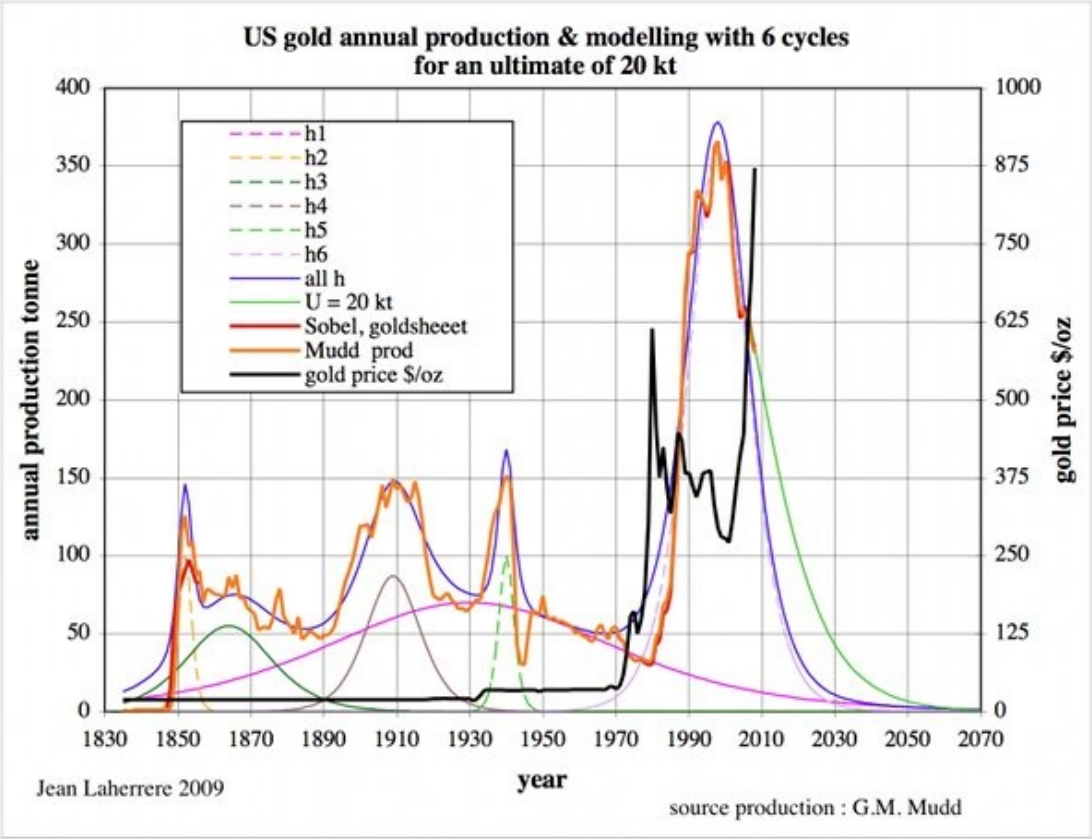


Figure 12: US annual gold production for an ultimate of 20 kt.

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 1960s, and declined to 2 g/t in 1980. In the 1990s the average grade remained just above 1 g/t, which is close to the threshold for economic extraction. The extrapolation of grade since 1980 up to 1993 (last value) leads towards a zero grade around now.

The largest production figure since 1980 was in Nevada: Jon Price Nevada Bureau of mines and geology 2007 *The world has changed: minerals in the 21st century* [pdf!].

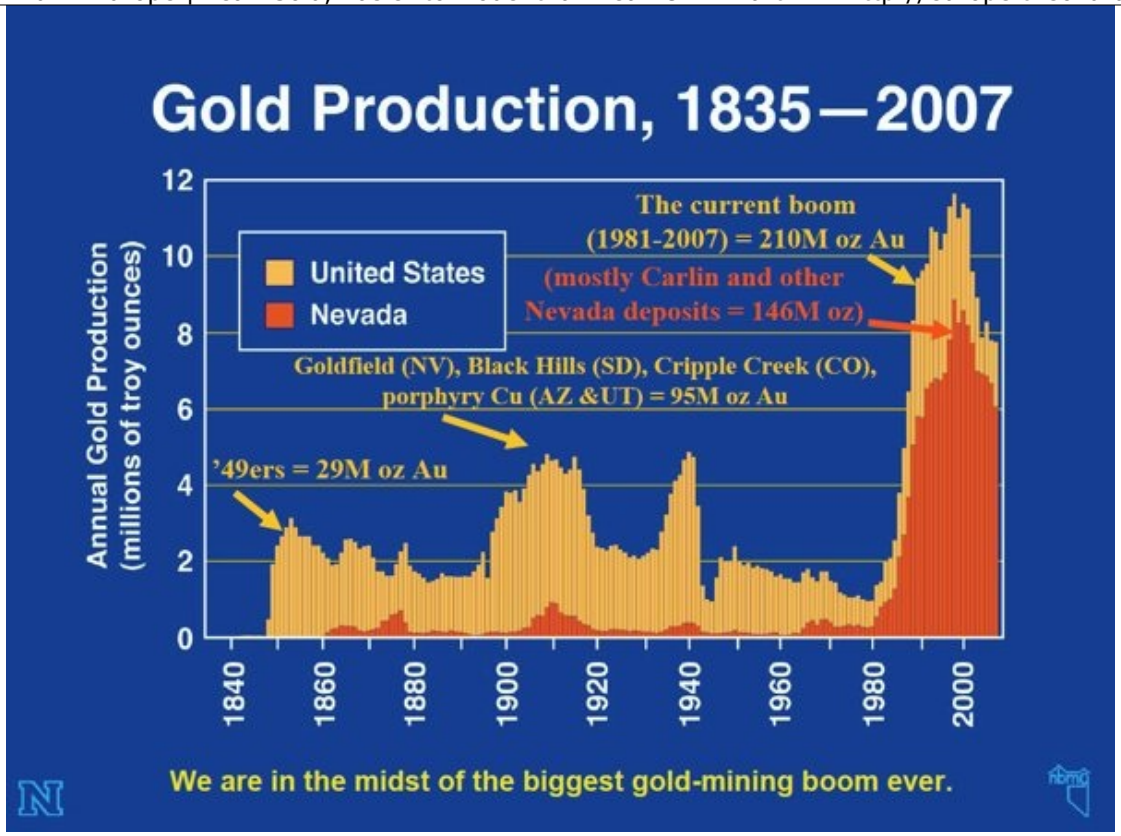


Figure 14: US annual gold production and Nevada contribution.

Canada

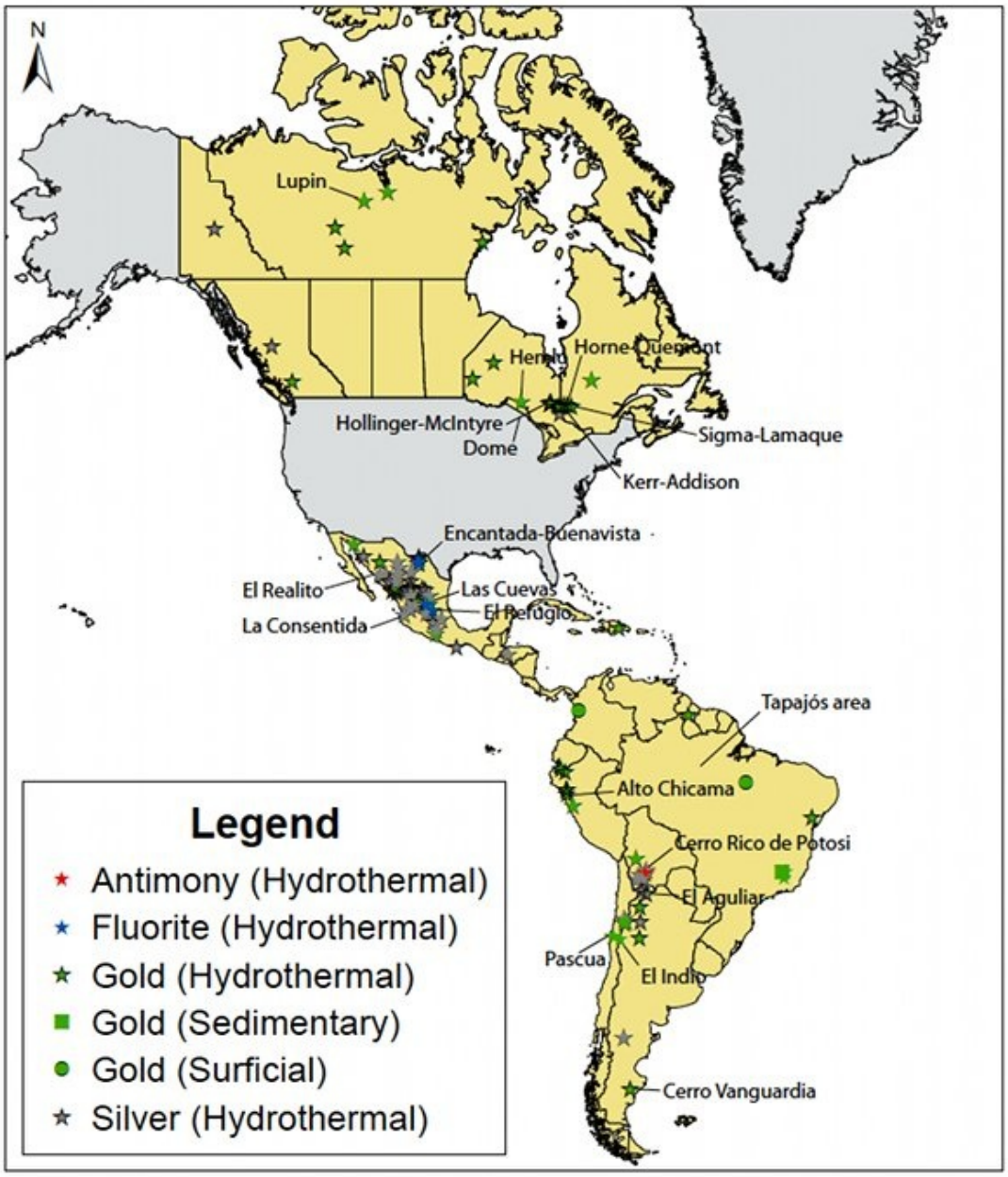


Figure 9c. Location and deposit type of major deposits of antimony, fluorspar (fluorite), gold, and silver.

Figure 15: Canada and Latin America gold map.

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

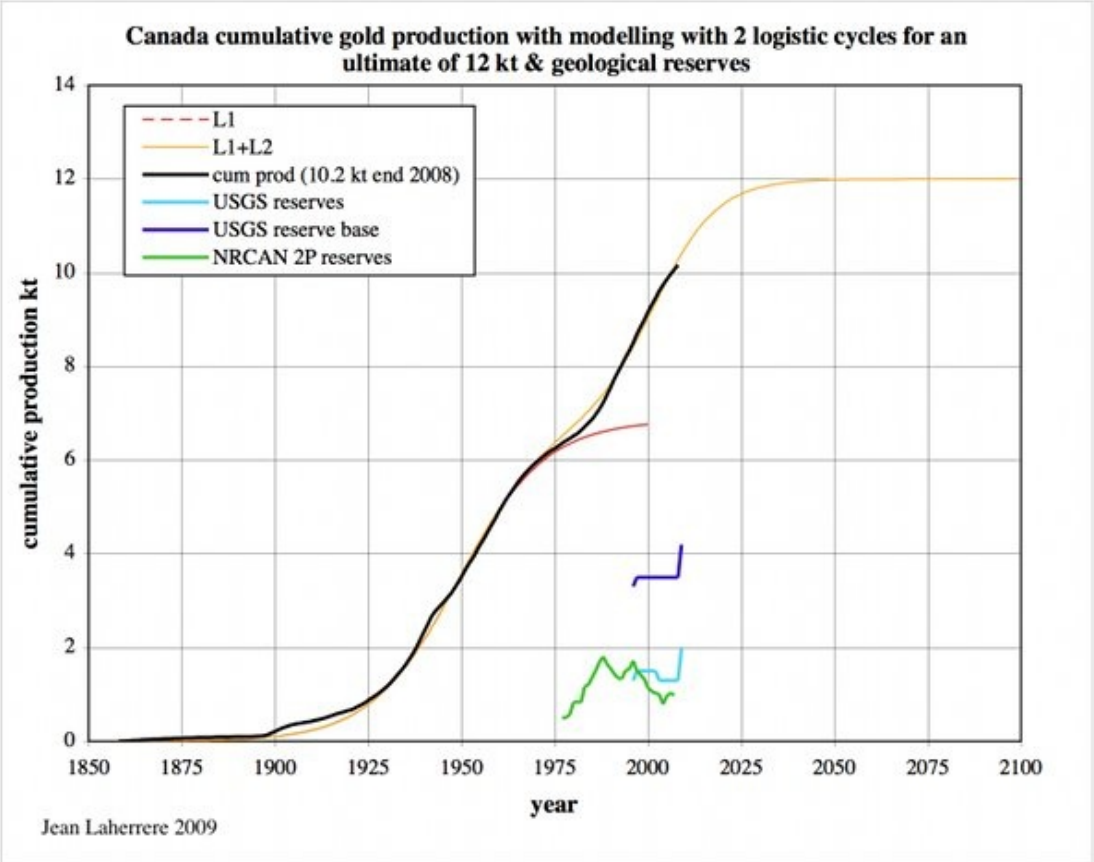


Figure 16: Canada cumulative gold production & modelling for an ultimate of 12 kt

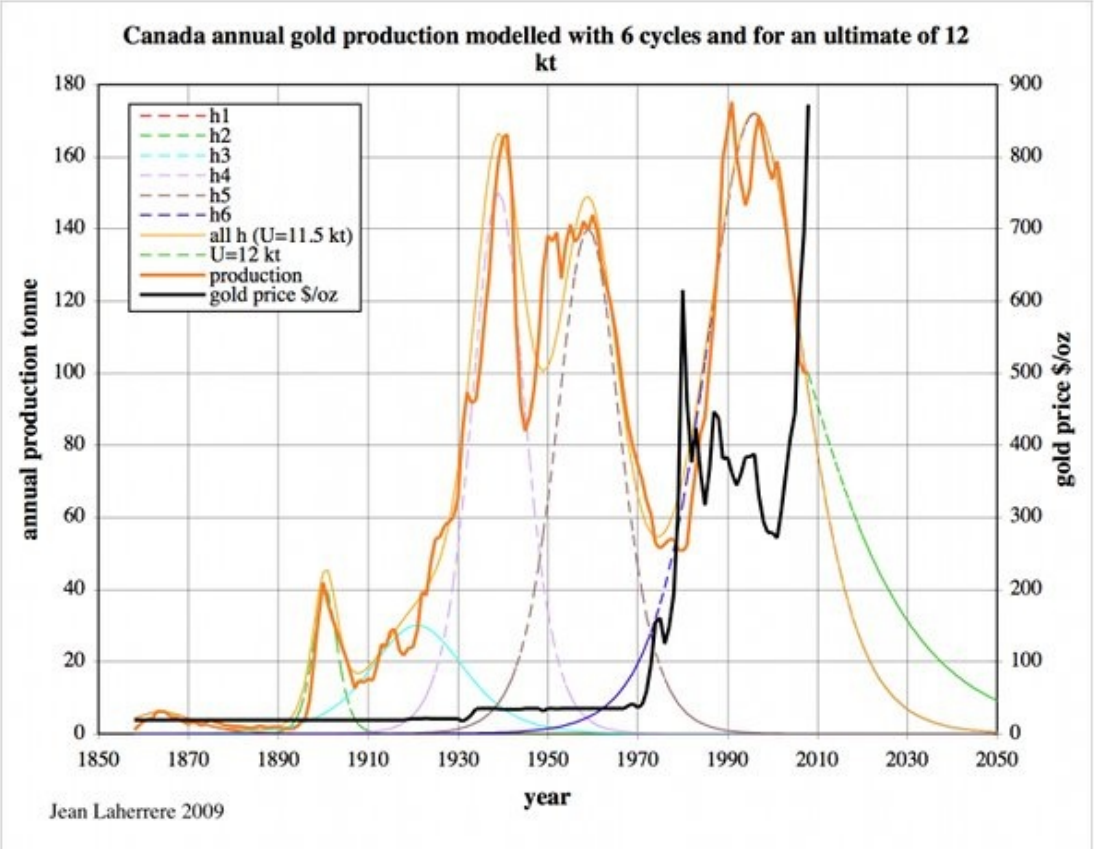


Figure 17: Canada annual gold production and modelling for an ultimate of 12 kt

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

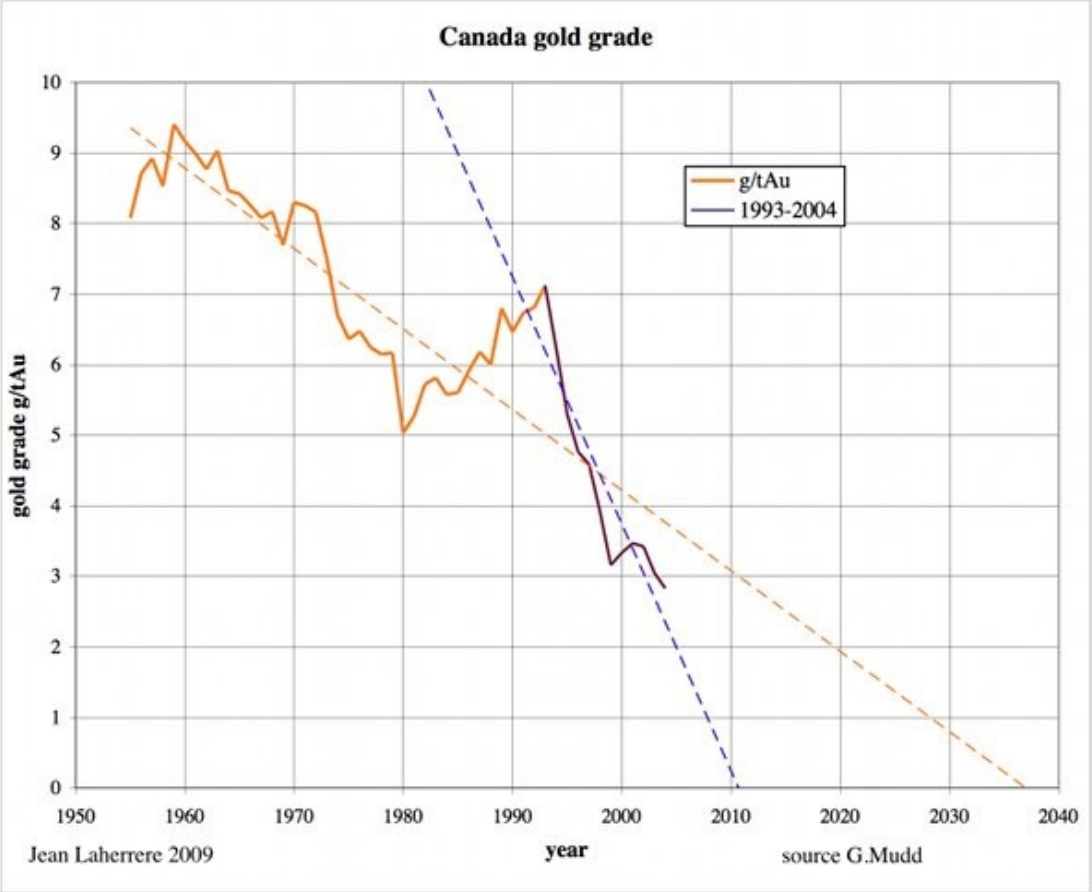


Figure 18: Canada gold grade.

Australia

The world's largest gold nugget was found in Australia (Victoria) in 1869 weighting 74 kg!

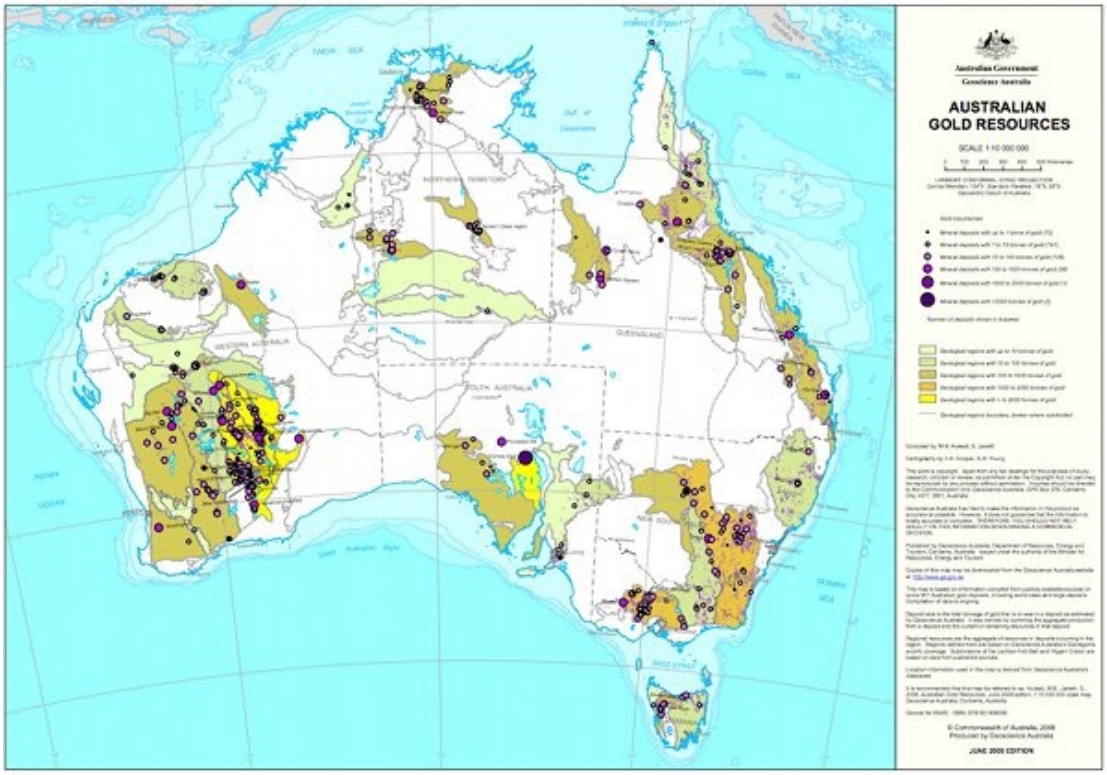


Figure 19: Australia gold map from www.ga.gov.au

Australia's cumulative gold production was about 12 kt in 2008, and can be modelled for an ultimate of 17 kt (USGS estimates reserves at 5 kt and reserve base at 6 kt).

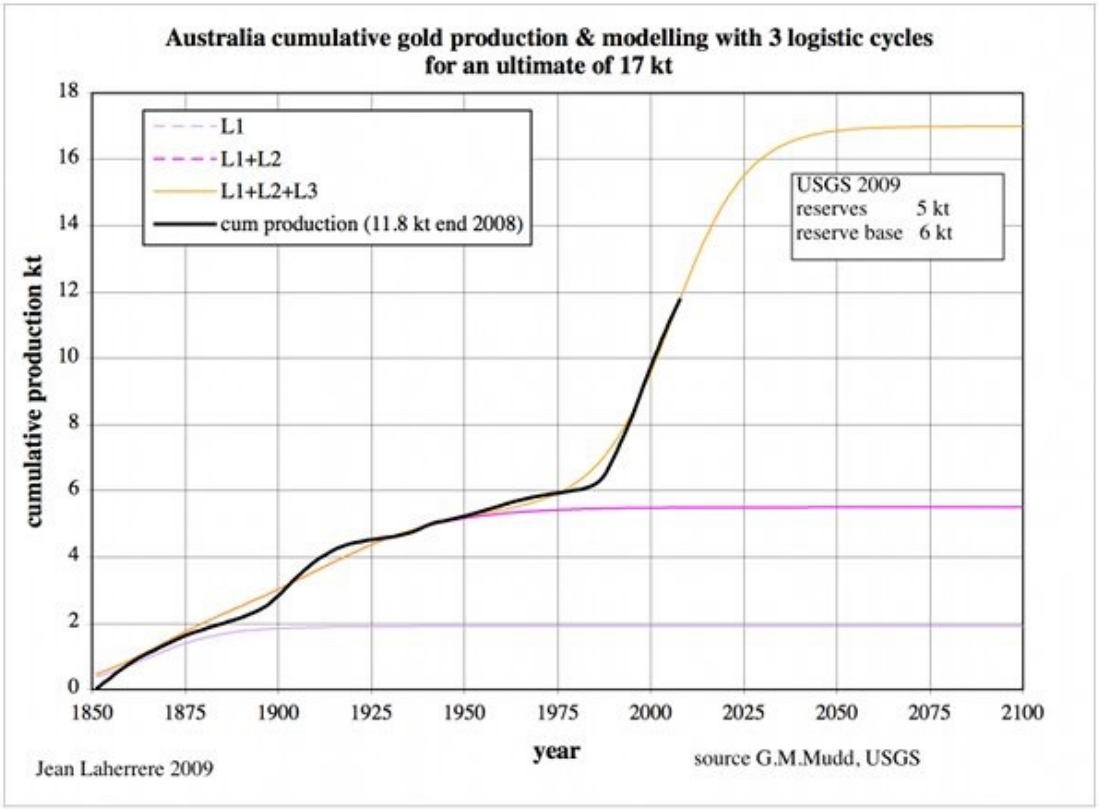


Figure 20: Australia cumulative gold production & modelling for an ultimate of 17 kt.

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

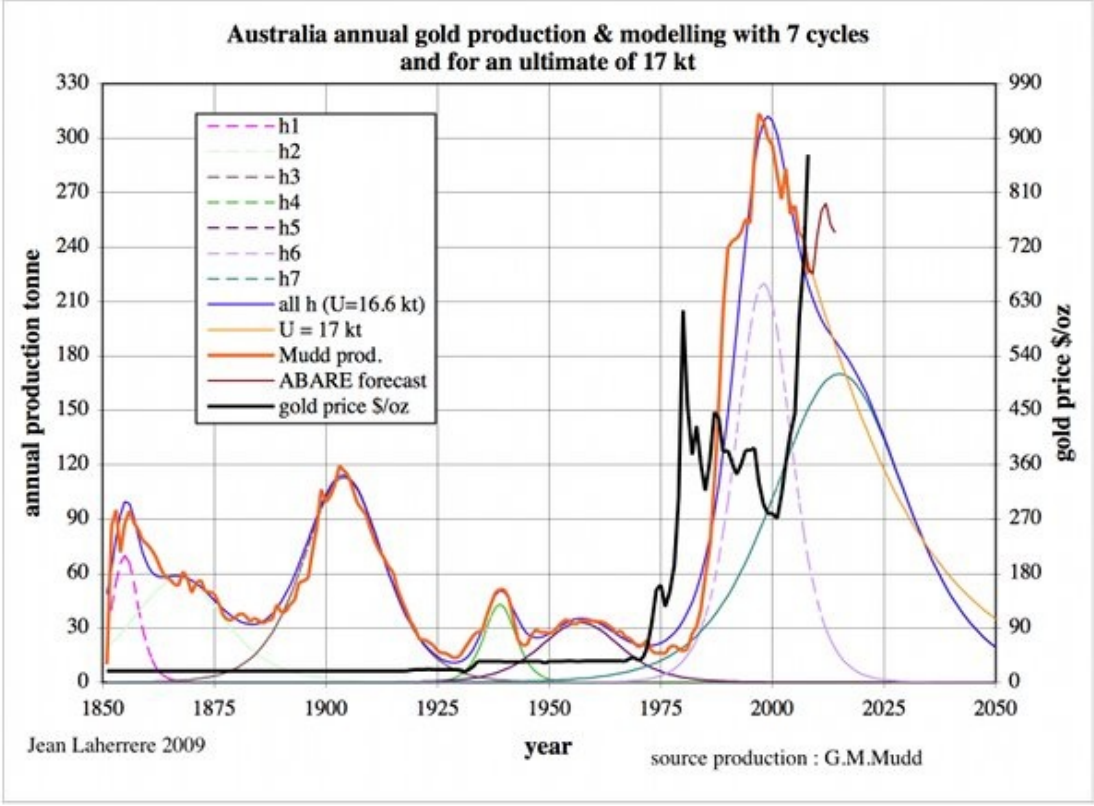


Figure 21: Australia annual gold production & modelling for an ultimate of 17 kt.

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

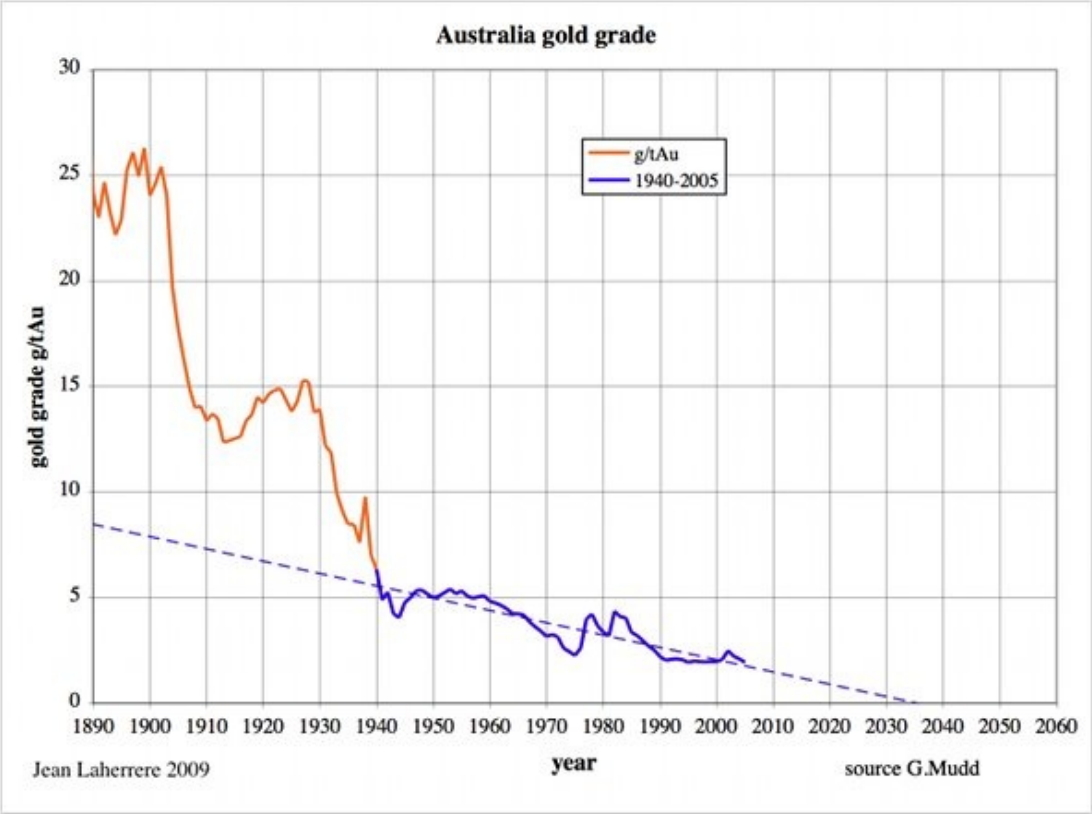


Figure 22: Australia gold grade

Brazil

Brazil's Gold Rush started in the 1690s, when the Bandeirantes discovered large gold deposits in the mountains of Minas Gerais [General Mines in Portuguese].

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)

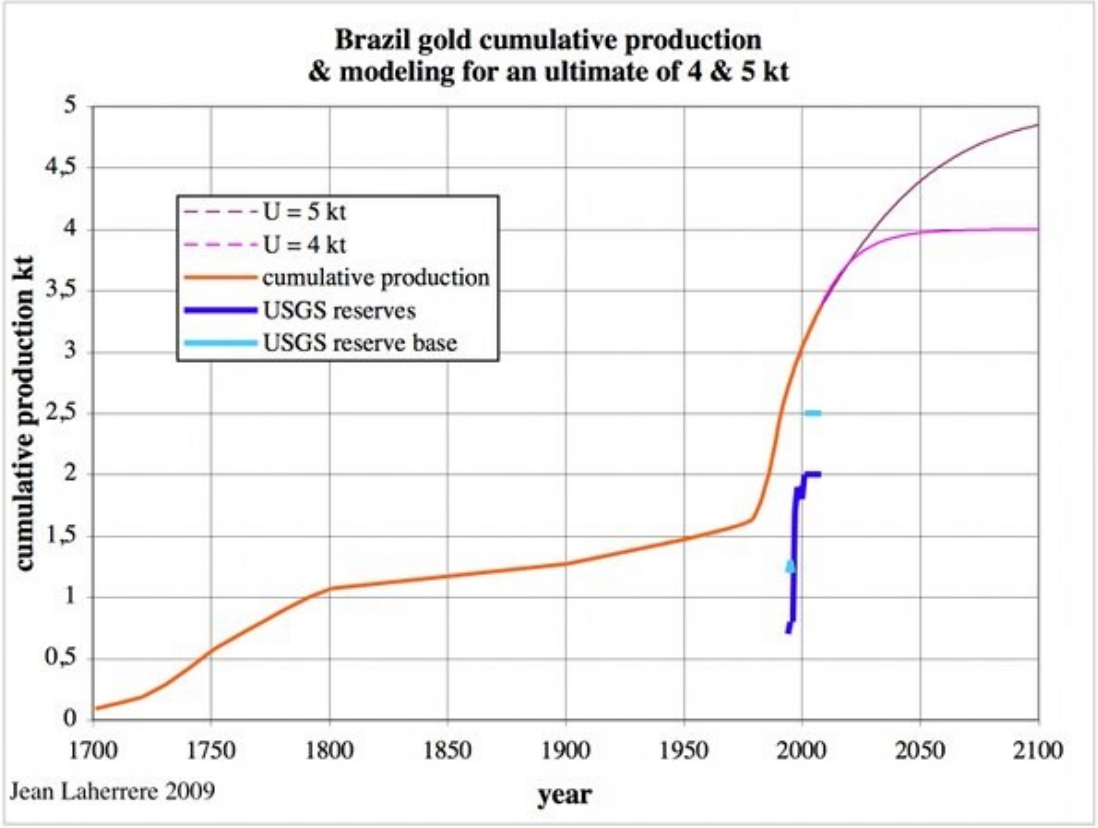


Figure 23: Brazil cumulative gold production and modelling for an ultimate of 4 kt & 5 kt

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

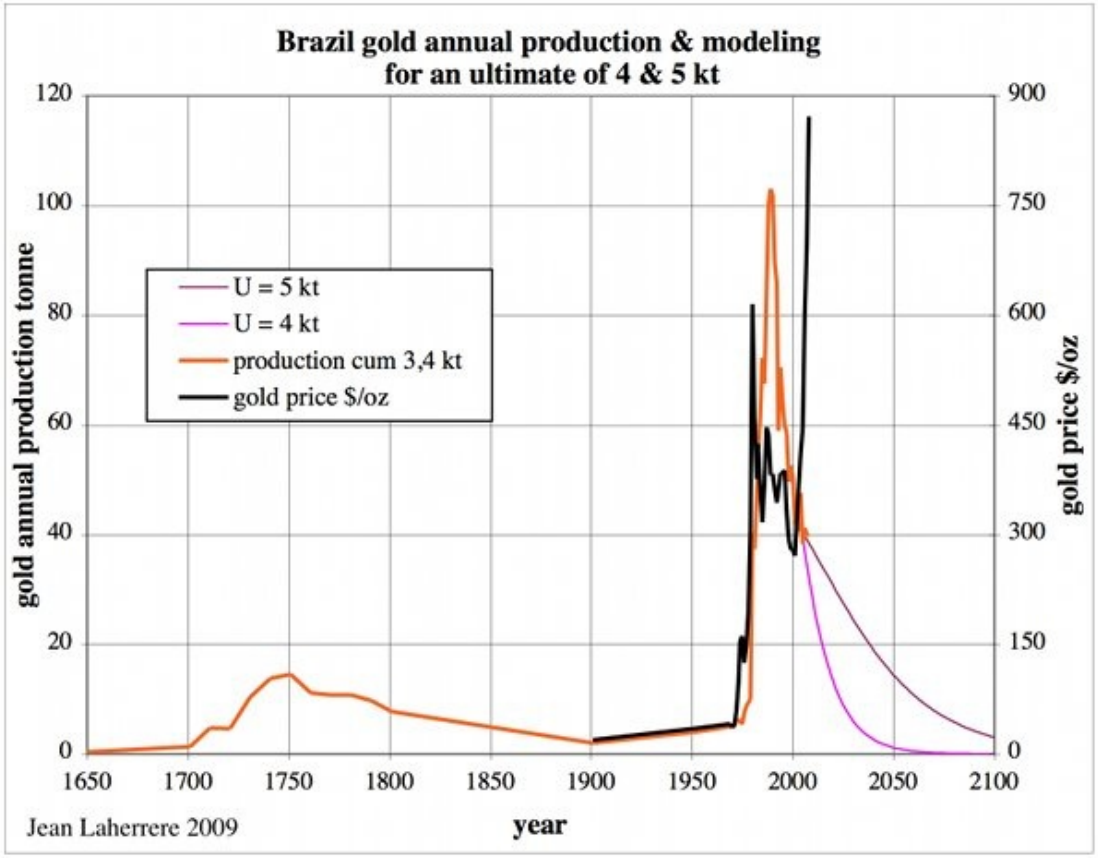


Figure 24: Brazil annual gold production and modelling for an ultimate of 4 kt & 5 kt

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 as too high, only the 4 kt ultimate being likely.

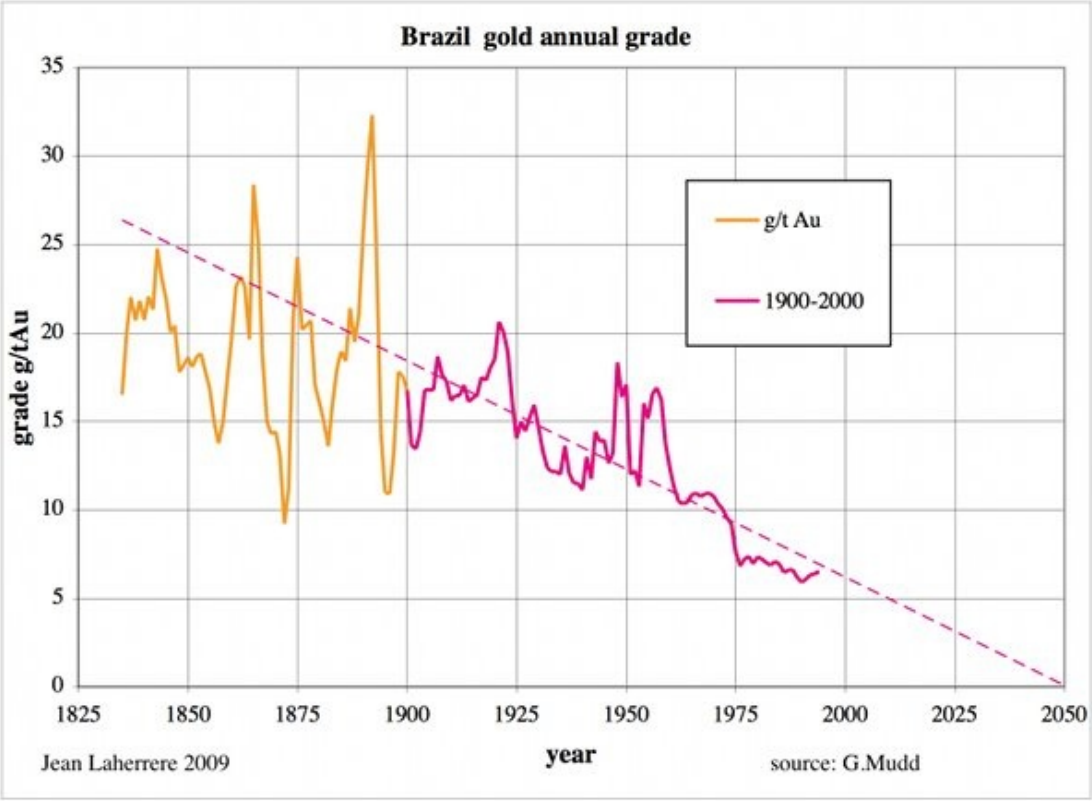


Figure 25: Brazil gold grade.

Peru

Gold was produced long before the Spanish conquest, but data starts in 1491. Cumulative gold production was 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.

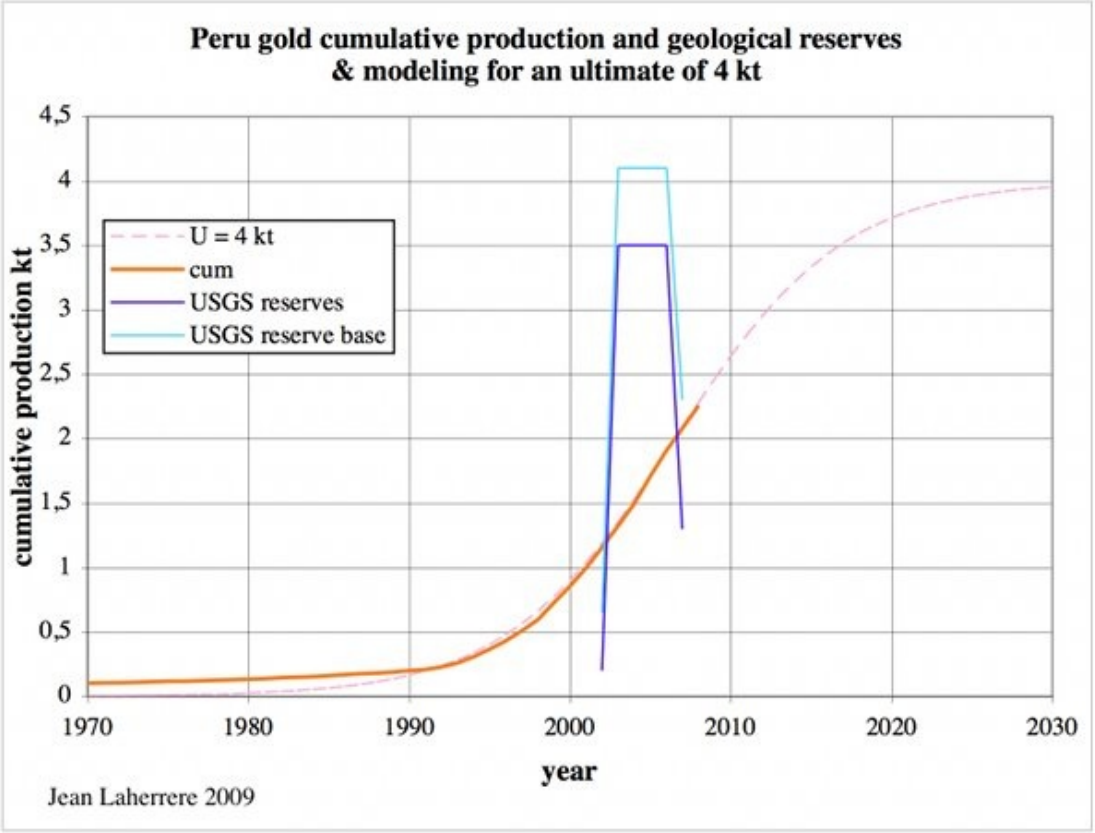


Figure 26: Peru cumulative gold production and modelling for an ultimate of 4 kt.

Peru's gold production has peaked in 2005 and will decline until 2020.

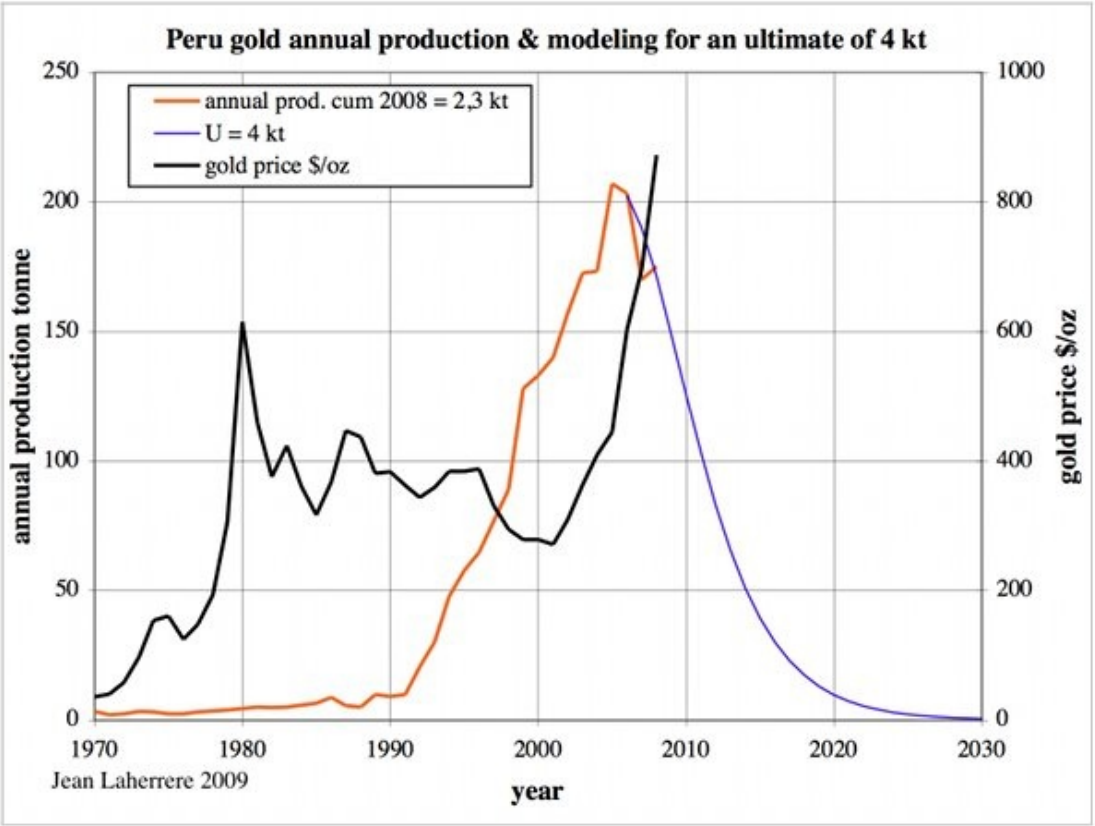


Figure 27: Peru annual gold production and modelling for an ultimate of 4 kt.

Mexico

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

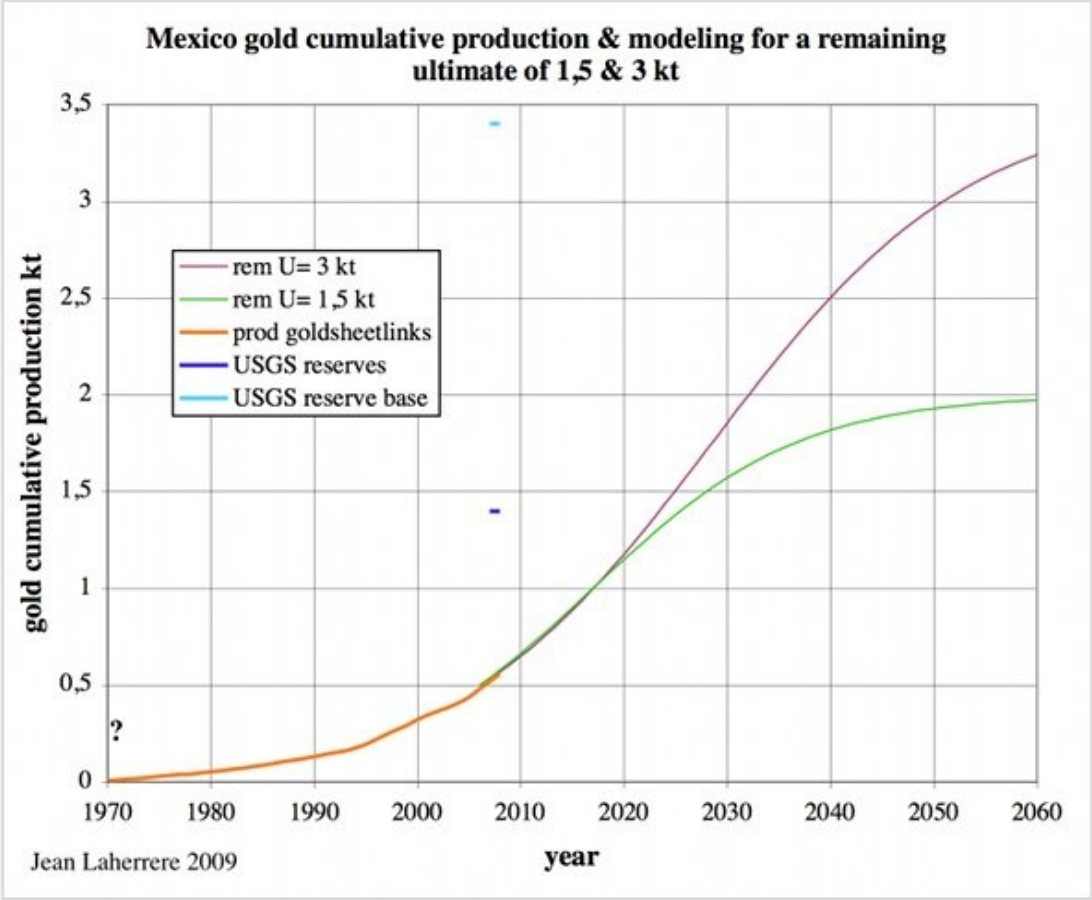


Figure 28: Mexico cumulative gold production and modelling for a remaining ultimate of 1.5 & 3 kt.

Mexico's gold production should peak about 2020, at around 100 t/a!

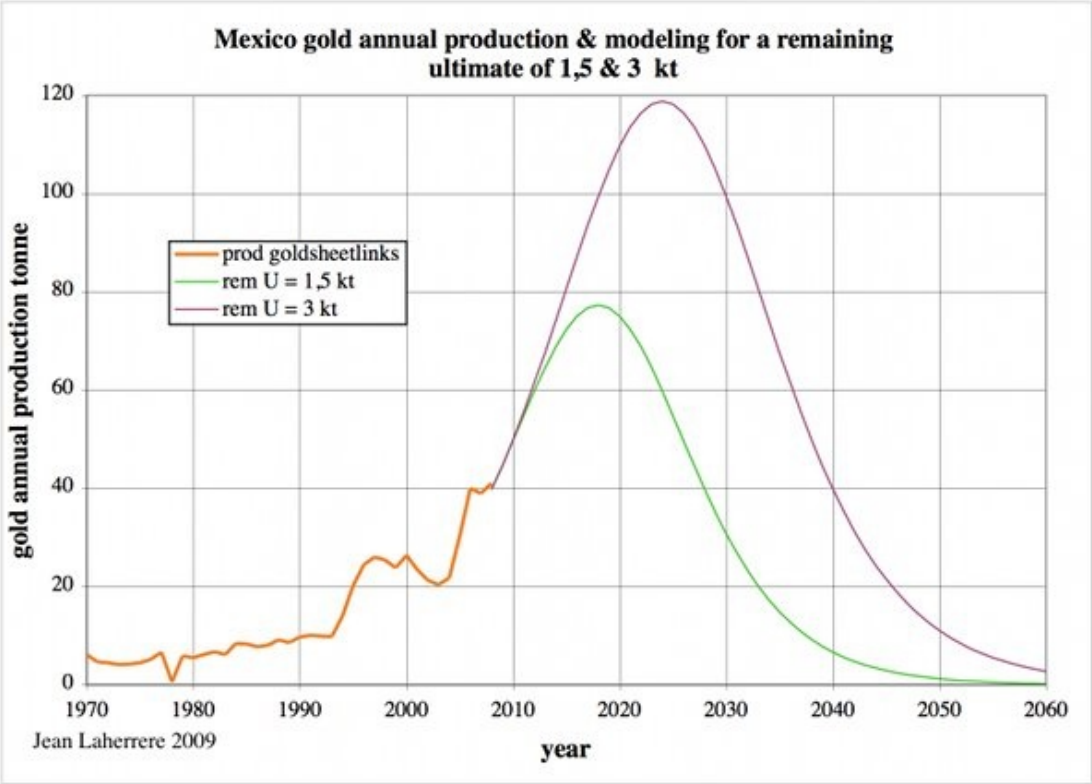


Figure 29: Mexico annual gold production & modelling for a remaining ultimate of 1.5 & 3 kt.

Chile

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

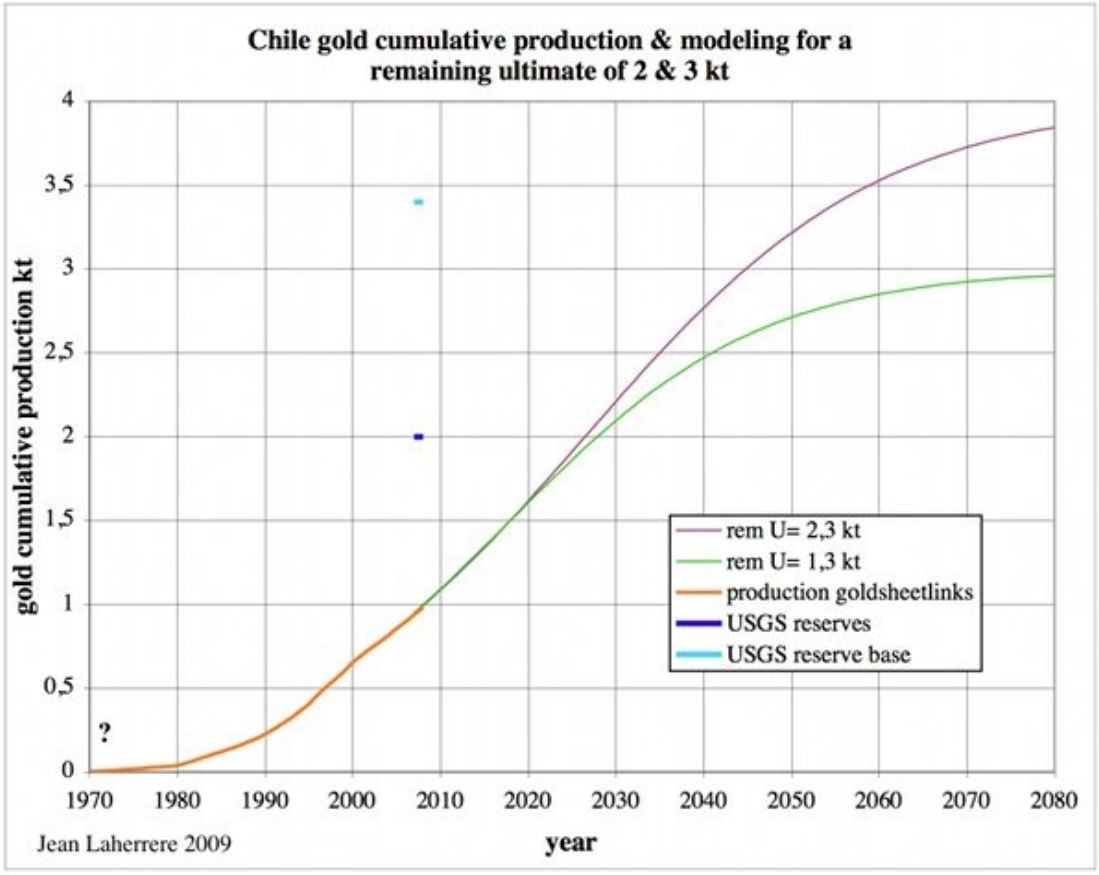


Figure 30: Chile cumulative gold production and modelling for a remaining ultimate of 2 & 3 kt.

Chile's gold production should peak around 2025 at 70 t/a.

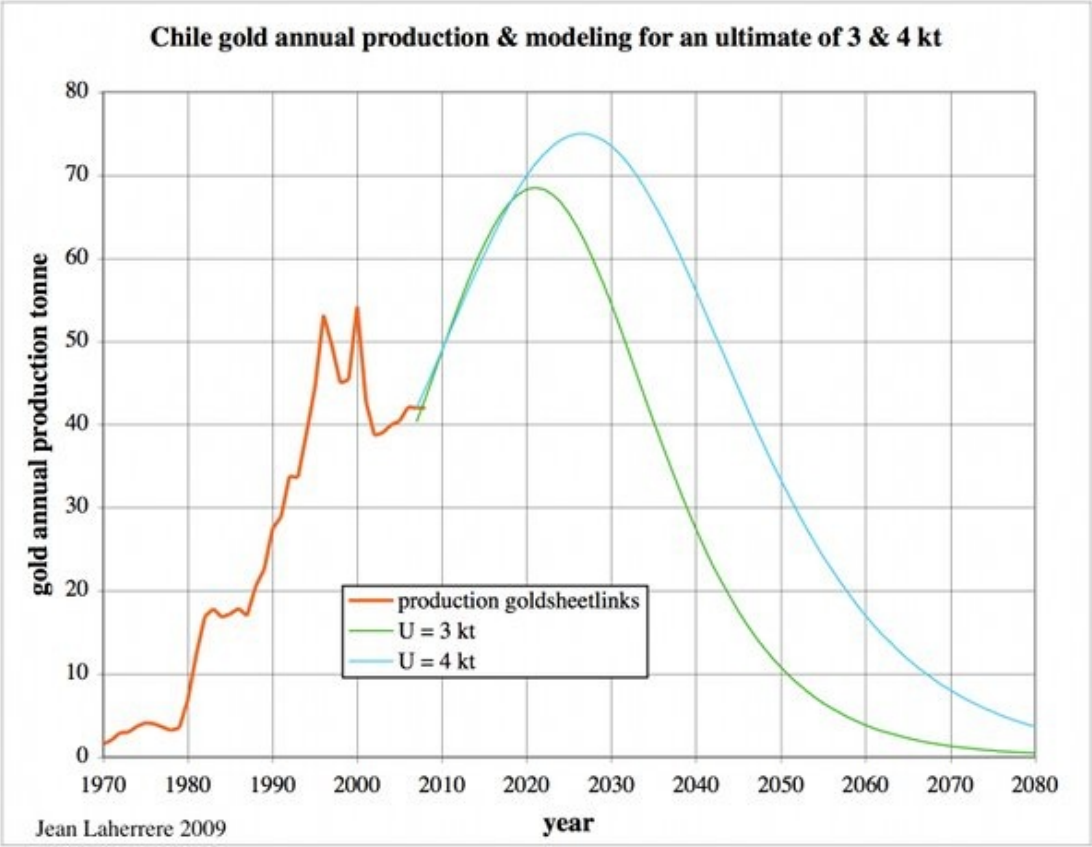
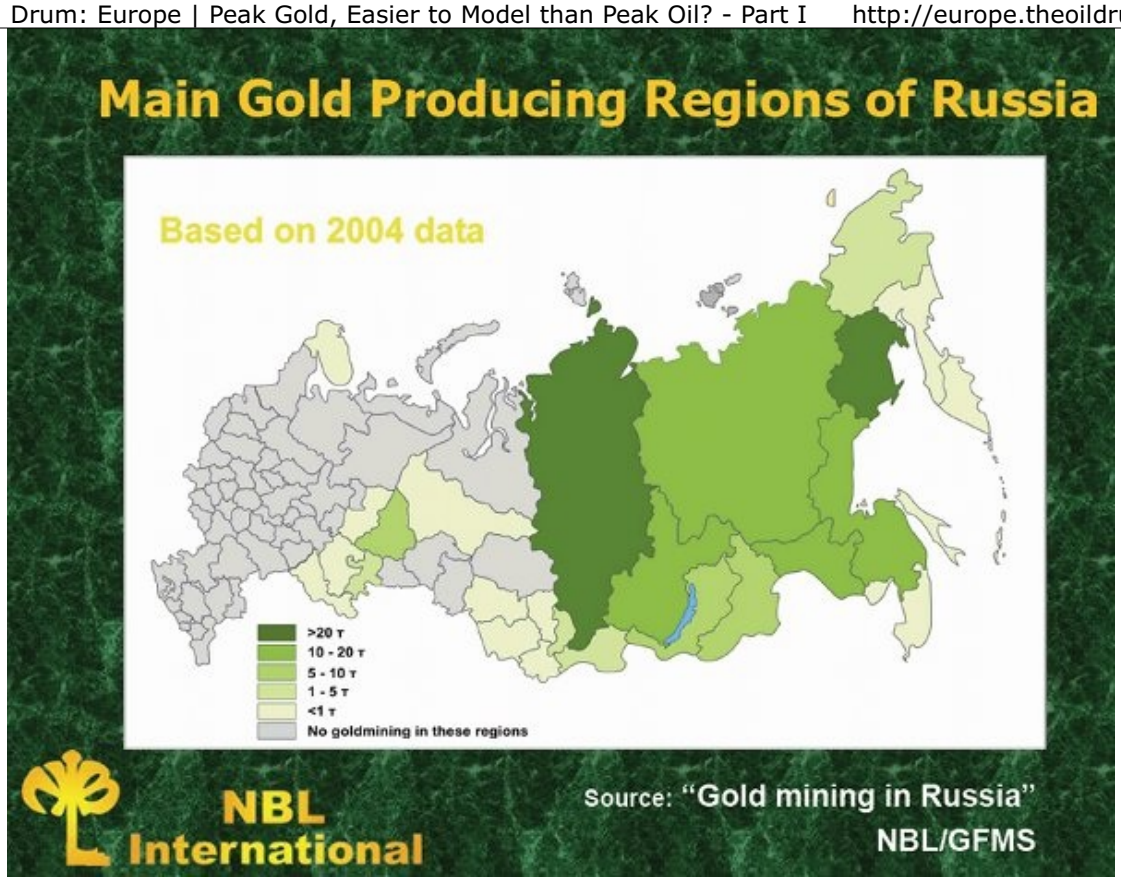


Figure 31: Chile annual gold production and modelling for a remaining ultimate of 2 & 3 kt.

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's (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.



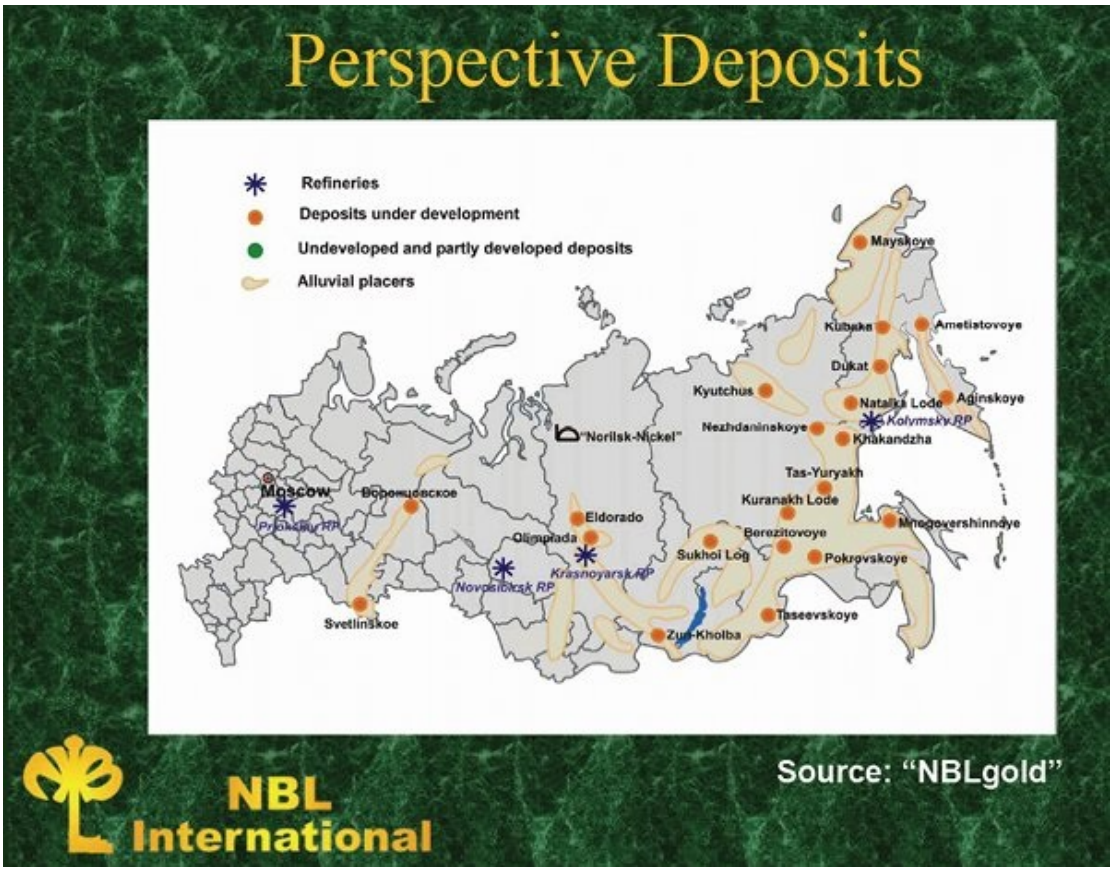


Figure 32: Russia gold map from NBL International

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

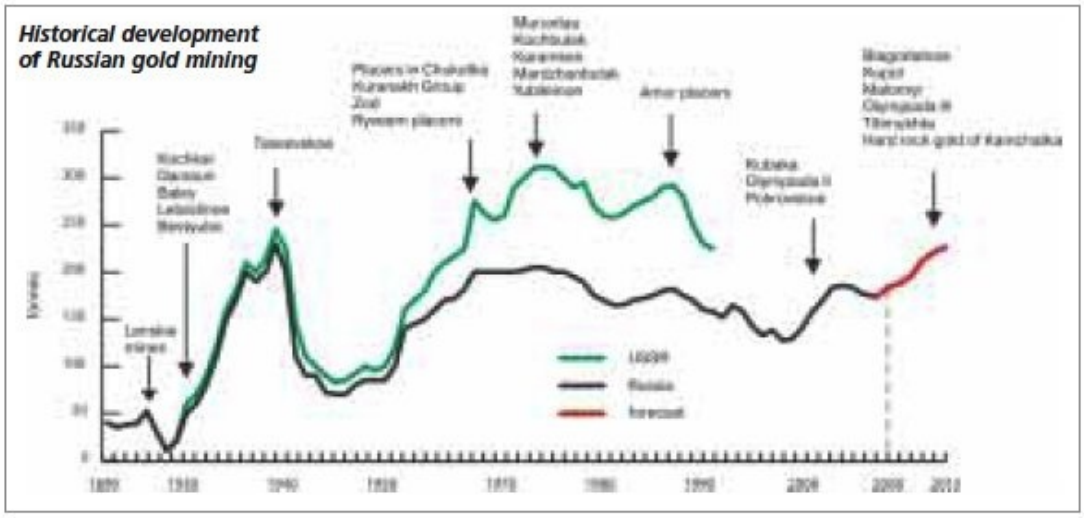


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Figure 33: Russia annual gold production from Leskov, head of NBL

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

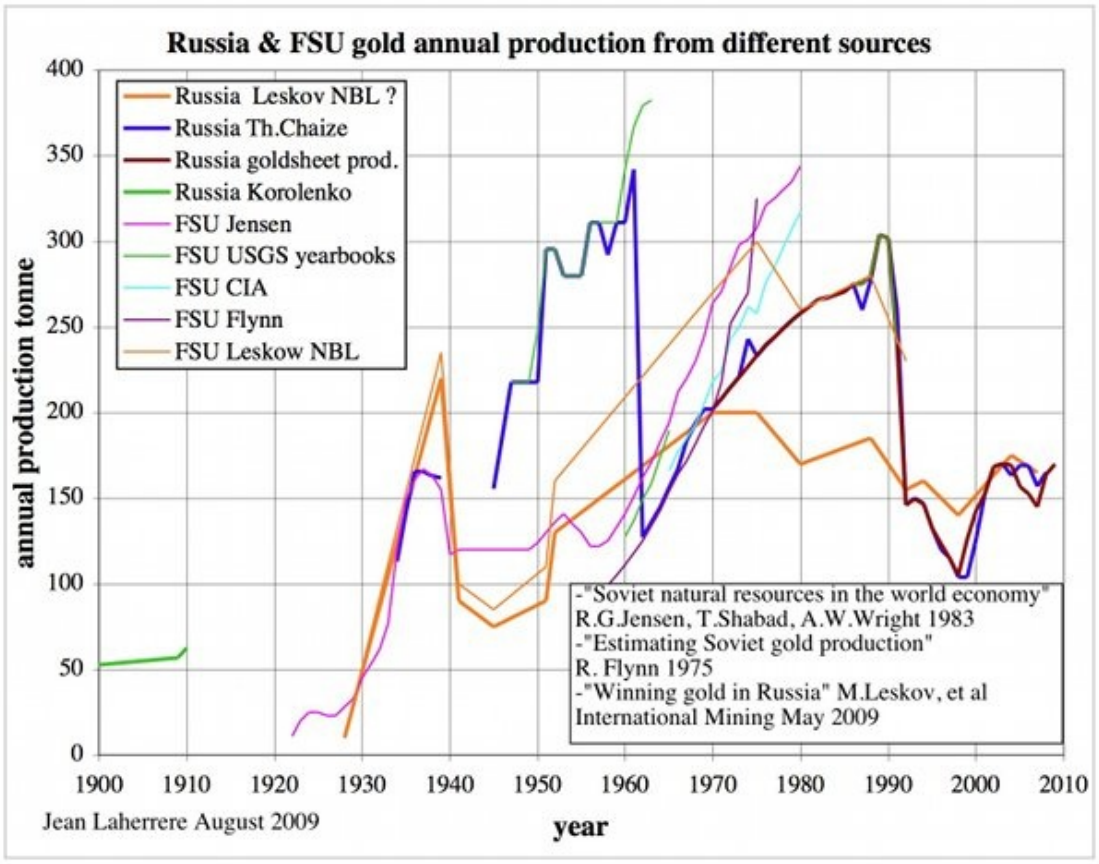

Figure 34: Russia annual gold production from different sources

Different data sources are:

1. The USGS minerals yearbooks. In the 1963 report, USSR production is reported at more than 10 Moz since 1950.

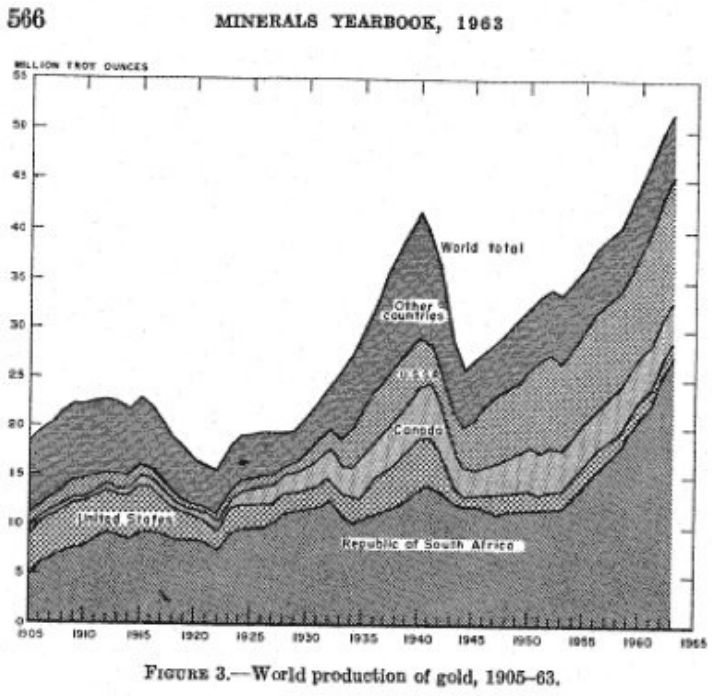

FIGURE 3.—World production of gold, 1905–63.

Figure 35: Annual gold production from USGS minerals yearbook 1963.

In the 1964 report, USSR production is shown as less than 5 Moz from 1942 to 1963 in a new graph for the past, but most researchers kept the previously reported annual data, which was not corrected.

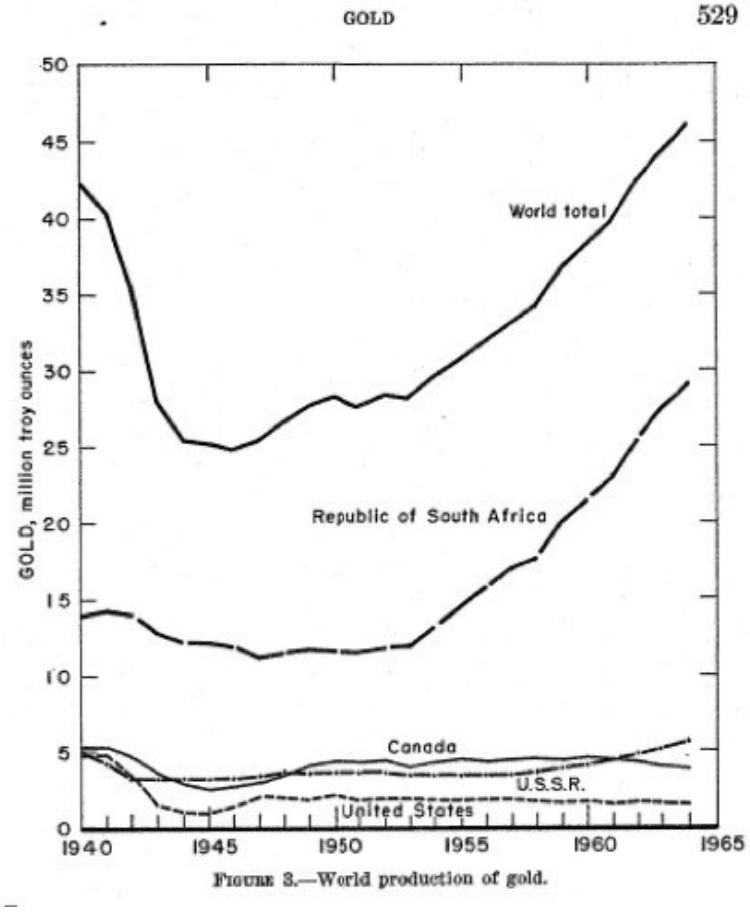

Figure 36: Annual gold production from USGS minerals yearbook 1964.

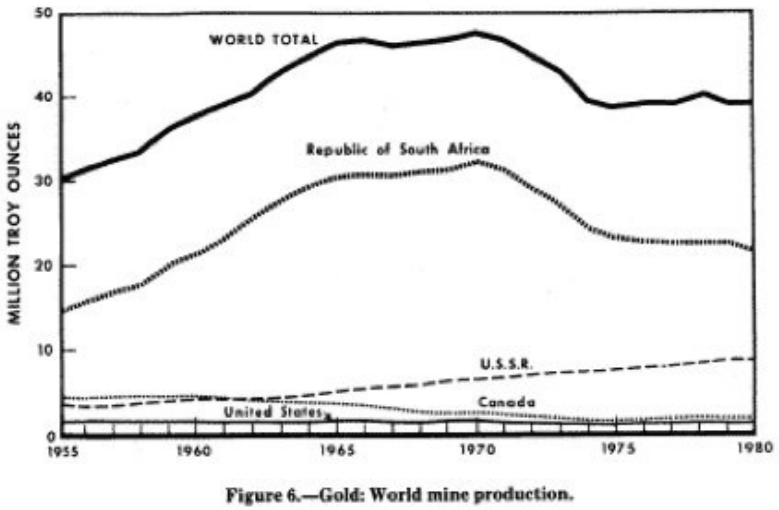

Figure 37: Annual gold production from USGS minerals yearbook 1980.

2. Robert G. Jensen, Theodore Shabad, Arthur W. Wright 1983 *Soviet natural resources in the world economy*.

3. Jon Price 2007 *The world has changed: minerals in the 21st century [pdf!]* Nevada Bureau of mines and geology.

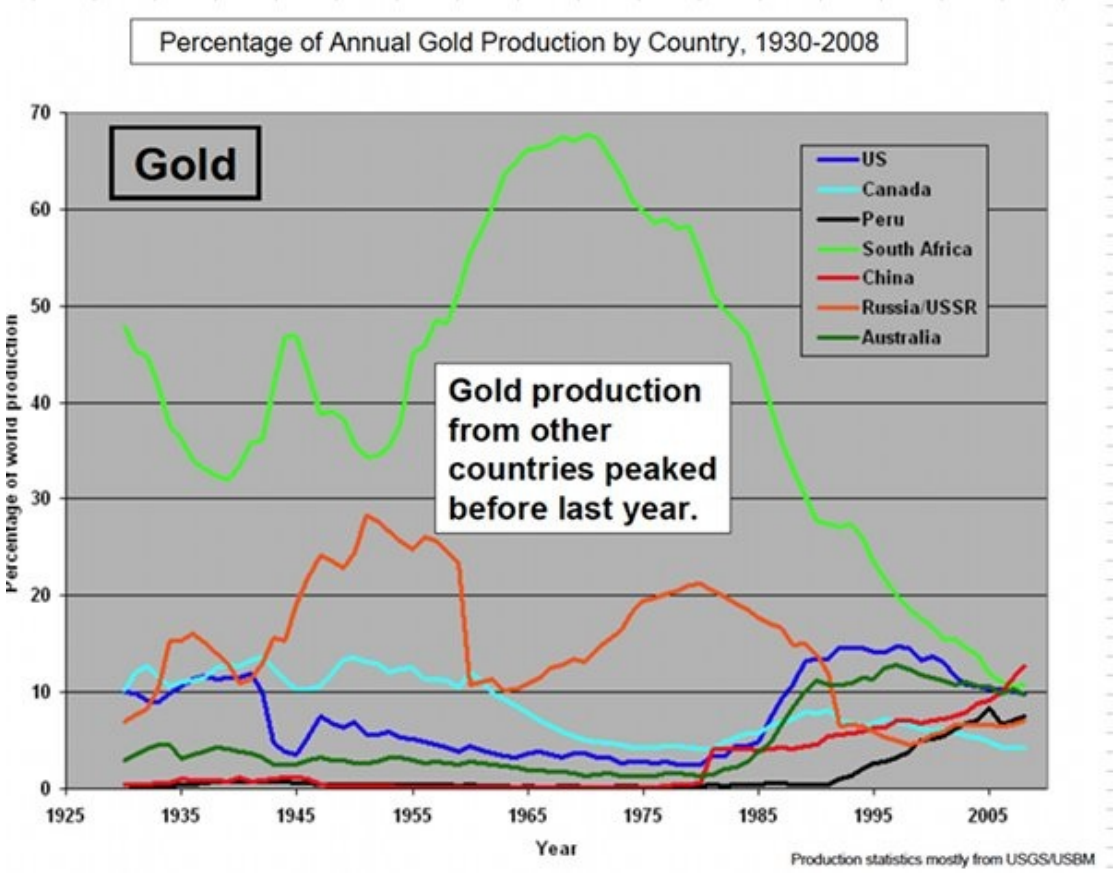

Figure 38: percentage of annual gold production by country from Price showing an incorrect collapse of Russia production in 1961

4.Thomas Chaize and his site.

5.V. Korolenko 2004 *Prospects for the Production and Processing of Gold in Russia.*

6. 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).

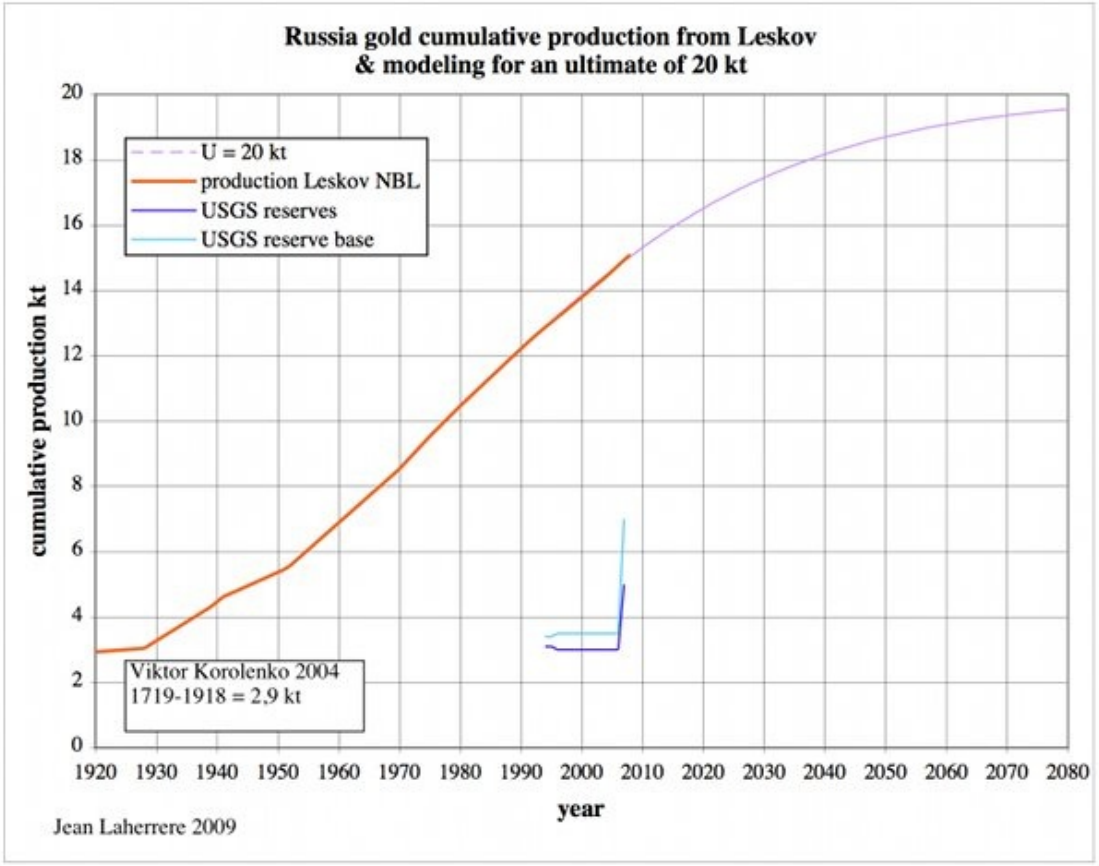

Figure 39: Russia cumulative gold production and modelling for an ultimate of 20 kt.

Russia's gold production should peak again around 2015 at 200 t/a and decline until 2060.

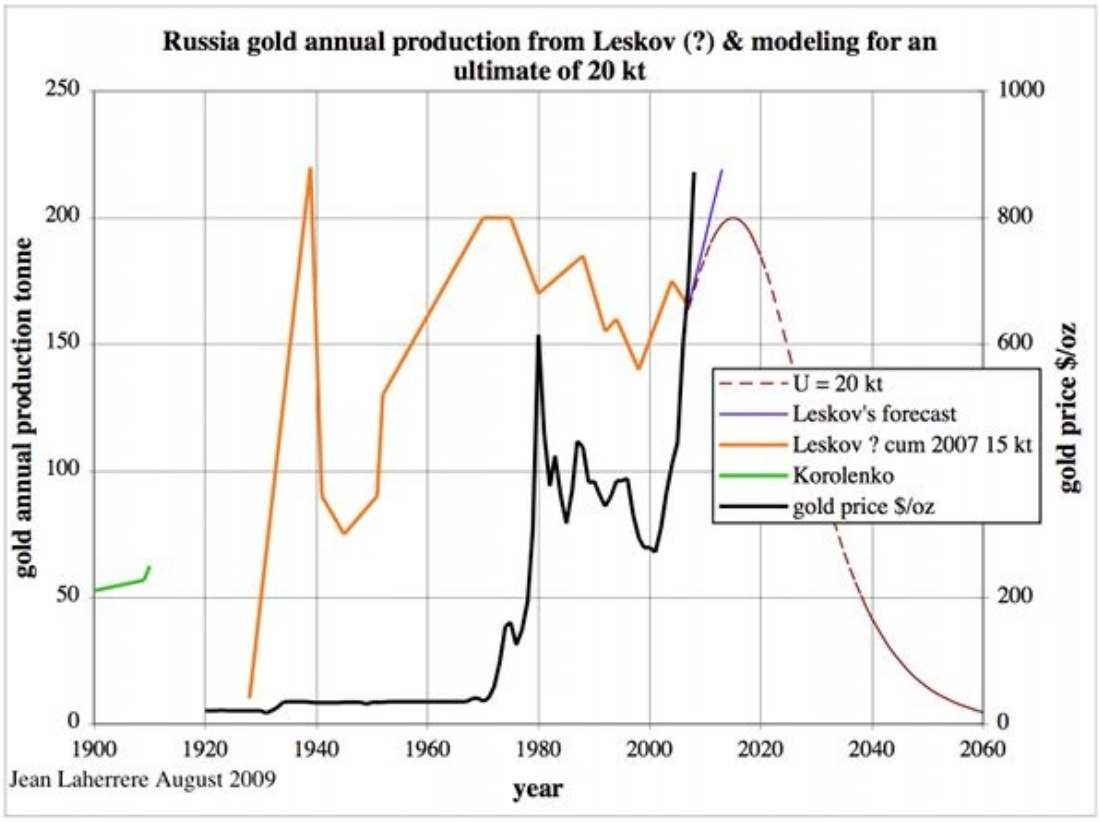

Figure 40: Russia annual gold production and modelling for an ultimate of 20 kt.

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).

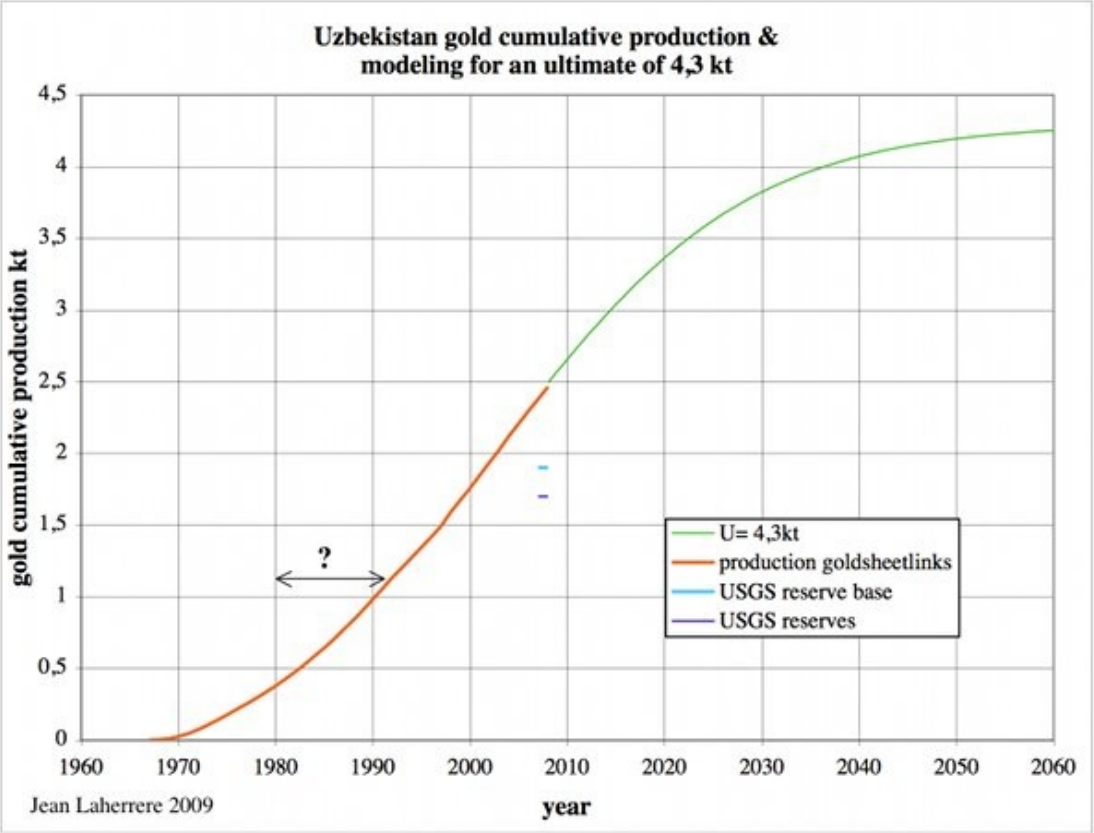

Figure 41: Uzbekistan cumulative gold production and modelling for an ultimate of 4.3 kt.

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

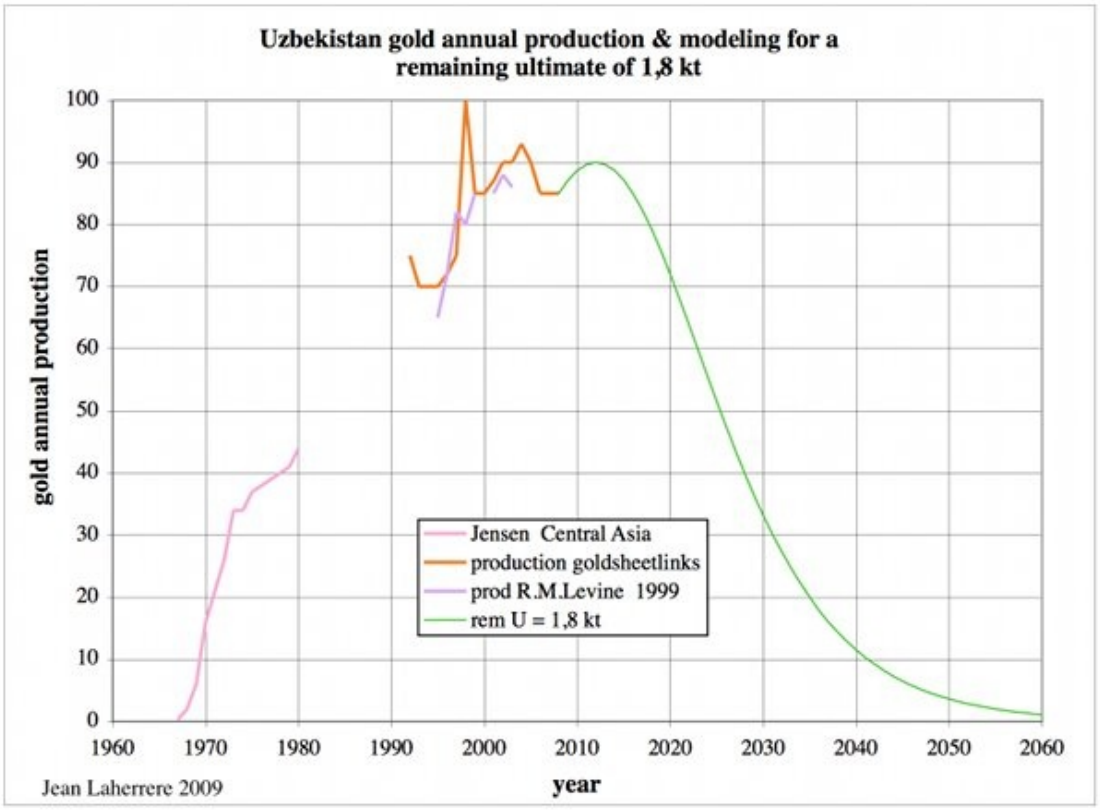

Figure 42: Uzbekistan annual gold production and modelling for an ultimate of 4.3 kt.

China

There are many gold deposits in China:

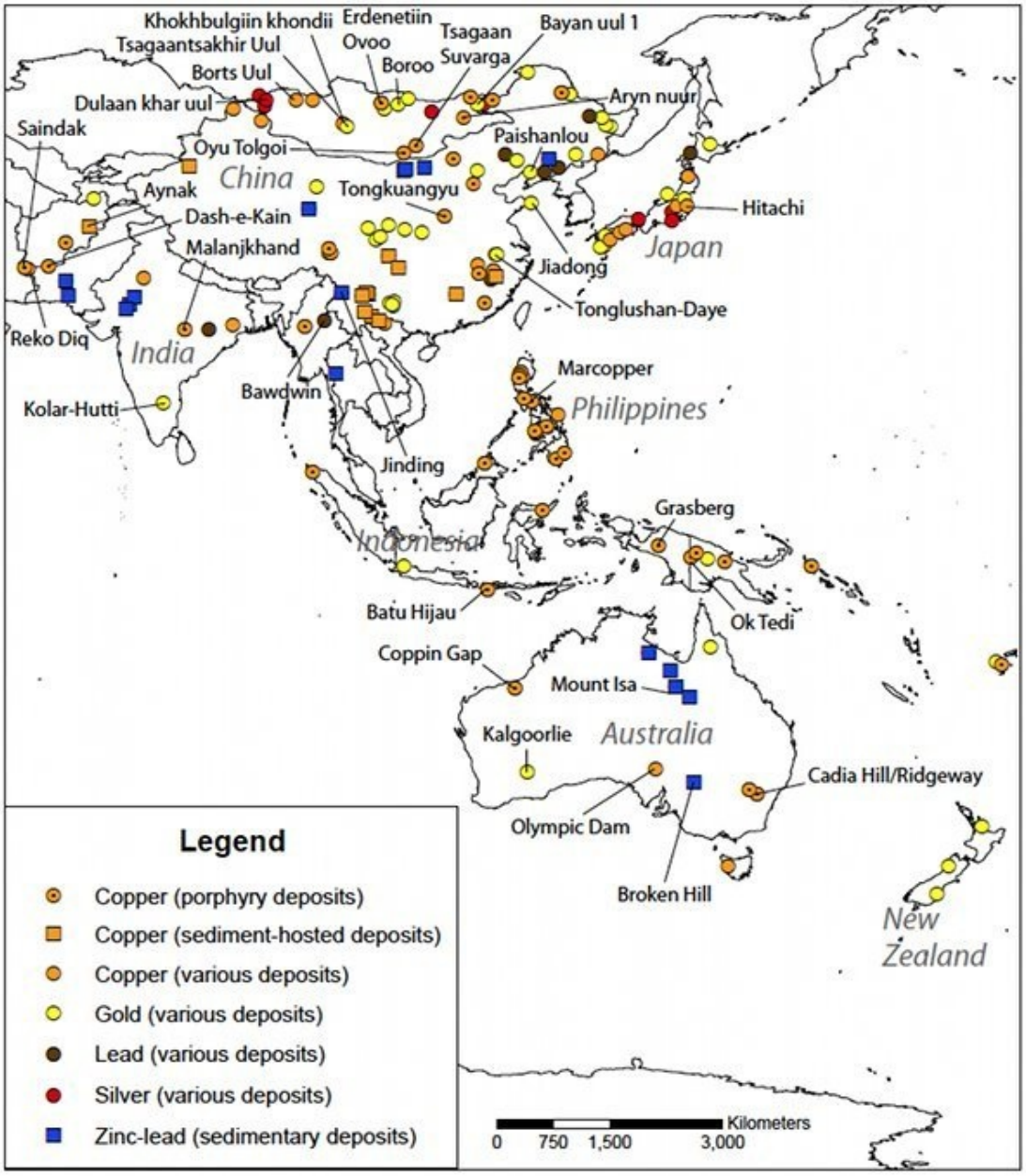

Figure 4A - Main nonfuel mineral deposits in the Asia and Pacific Region. The deposits are tabulated on table 2.

Figure 43: China gold deposits map from USGS 2005-1294.

China's gold production was low from 1930 to 1970, but before that it is unknown. Gold has been known in China since 1091 B.C. [pdf!] when little squares of gold were legalized in China as a form of money.

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

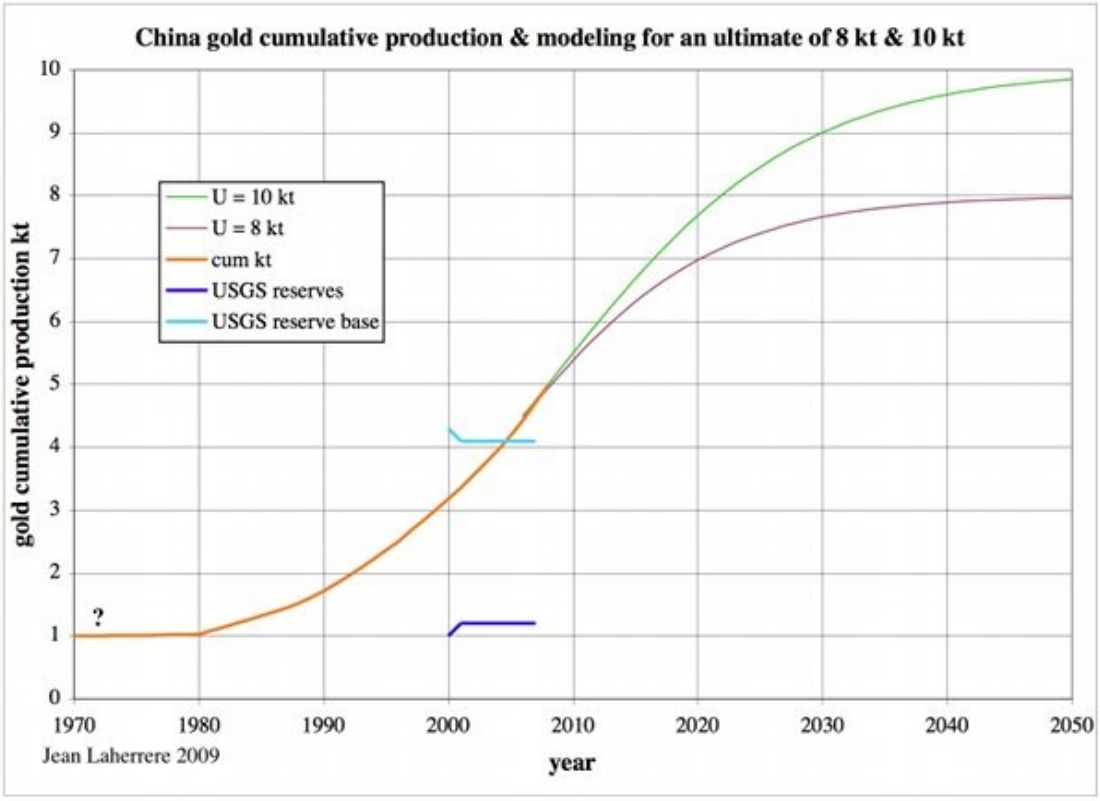

Figure 44: China cumulative gold production and modelling for an ultimate of 8 & 10 kt.

China's annual gold production should peak between 2010 and 2015 and then decline sharply.

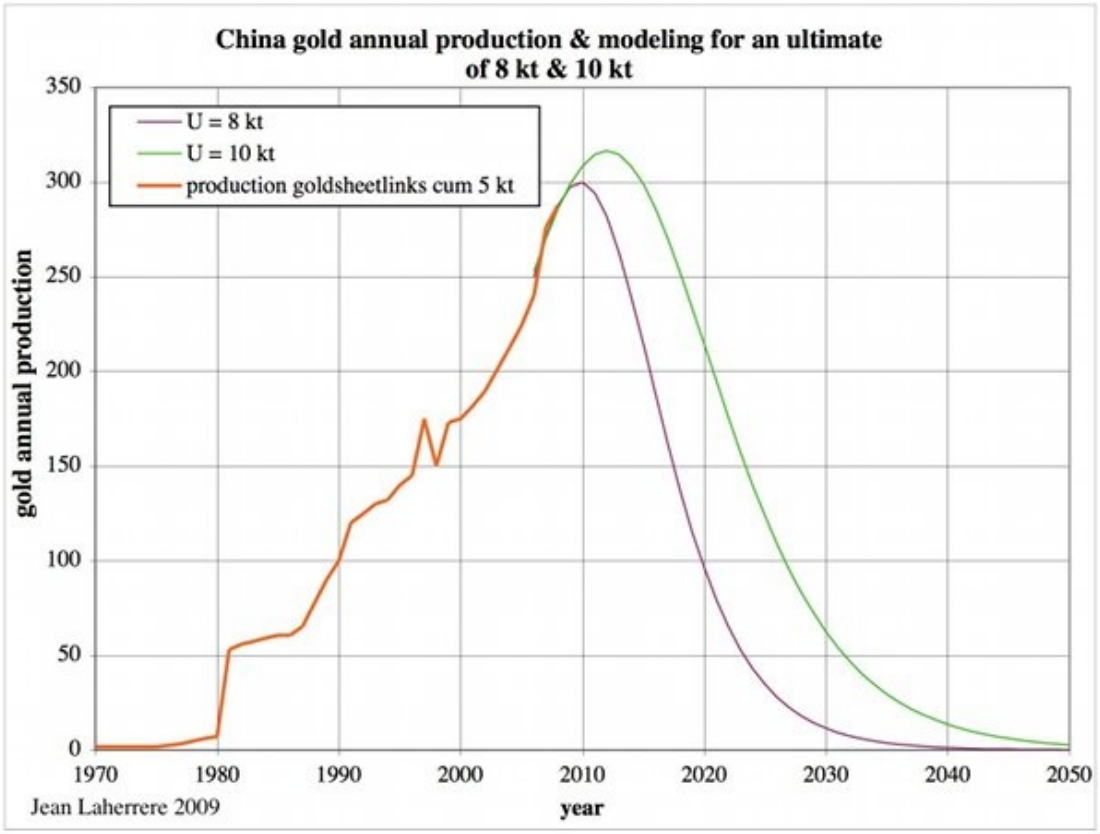

Figure 45: China annual gold production and modelling for an ultimate of 8 & 10 kt.

Indonesia

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

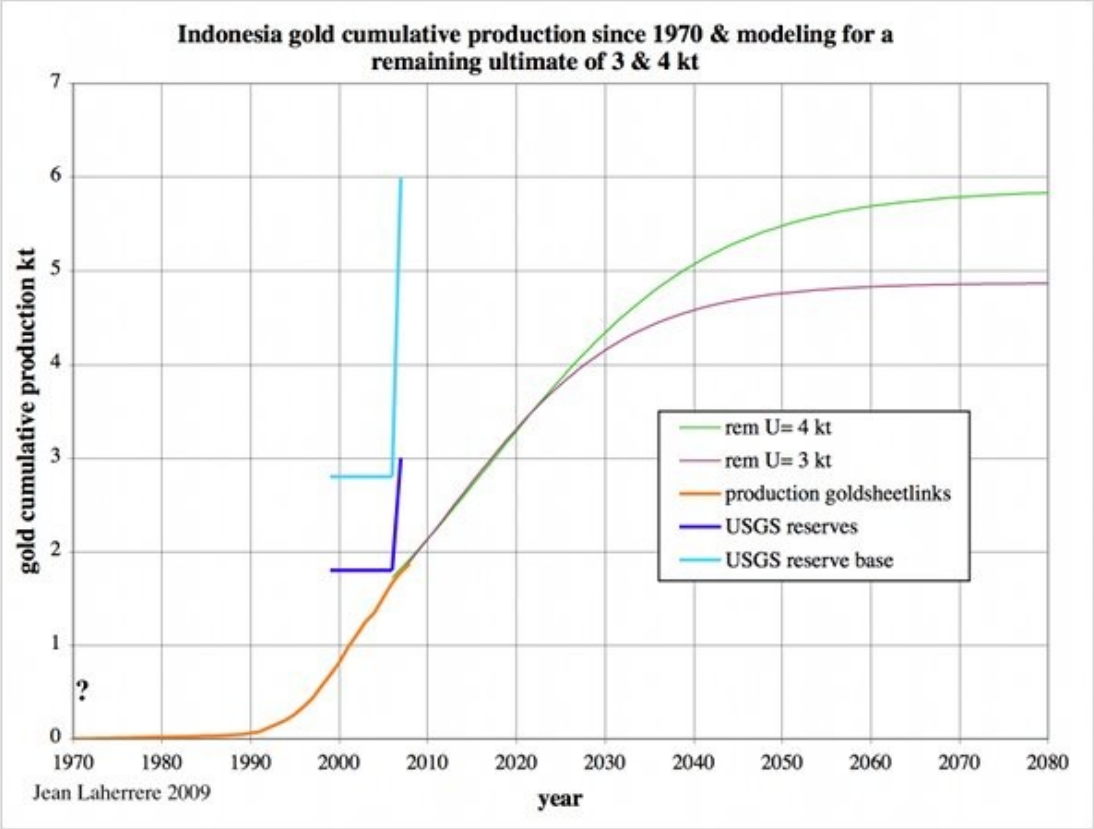

Figure 46: Indonesia cumulative gold production and modelling for a remaining ultimate of 3 & 4 kt.

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:

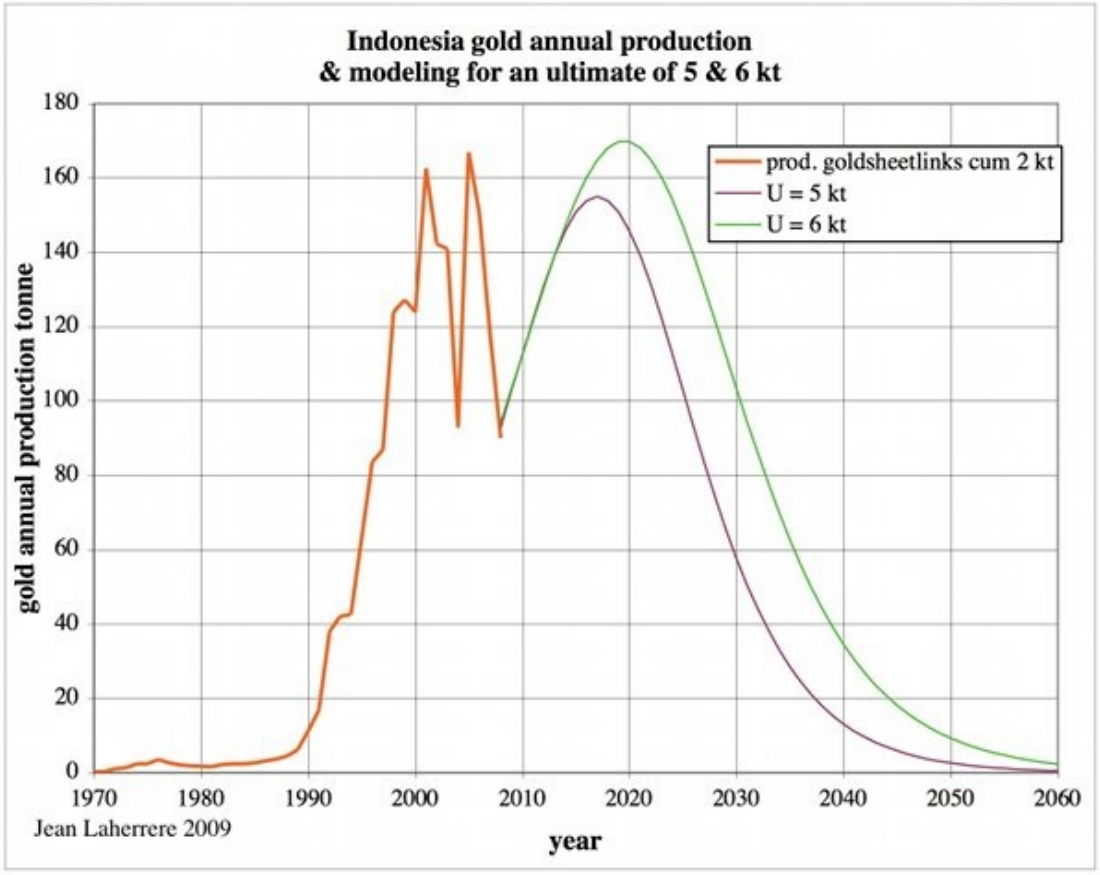

Figure 47: Indonesia annual gold production and modelling for an ultimate of 5 & 6 kt.

Papua New Guinea (PNG)

PNG's cumulative gold production was at 1.6 kt in 2008 and is modelled for ultimates of 3 & 4 kt (USGS reports reserves at 1.3 kt and the reserve base at 2.3 kt).

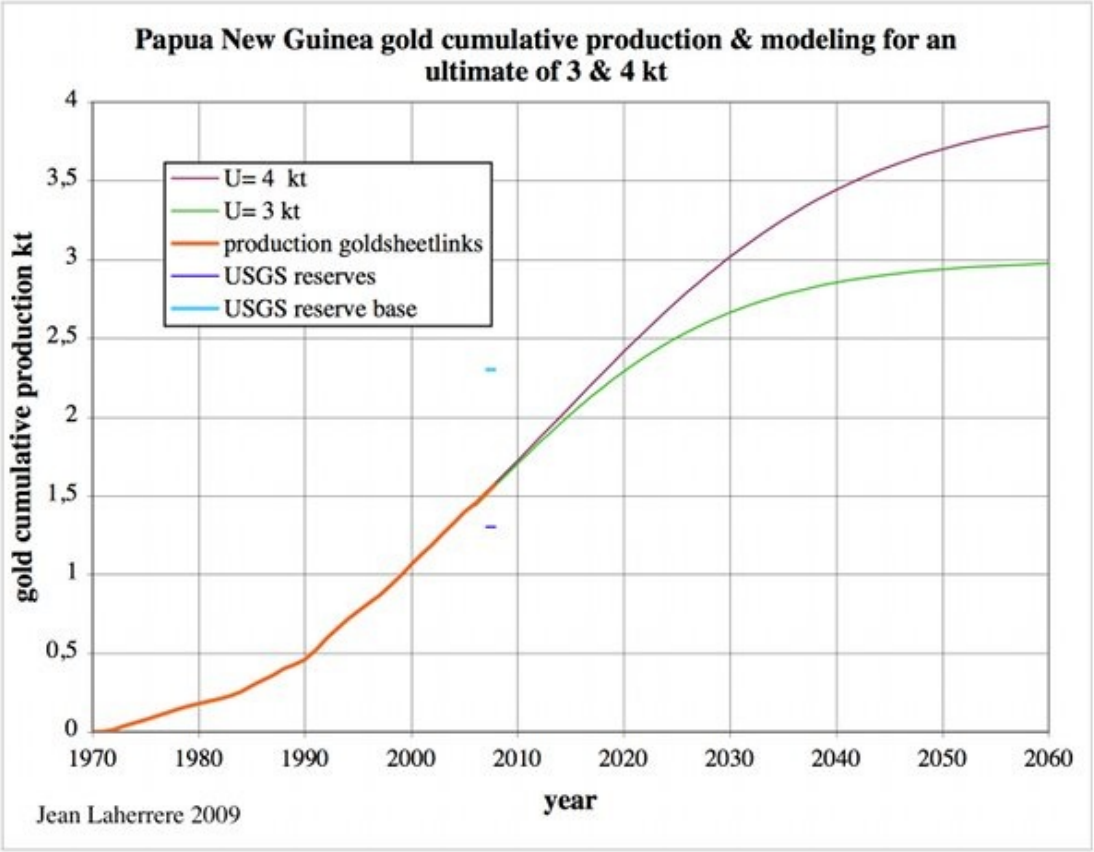

Figure 48: PNG cumulative gold production and modelling for ultimates of 3 & 4 kt.

PNG's annual gold production should peak during the 2010s and decline until 2050.

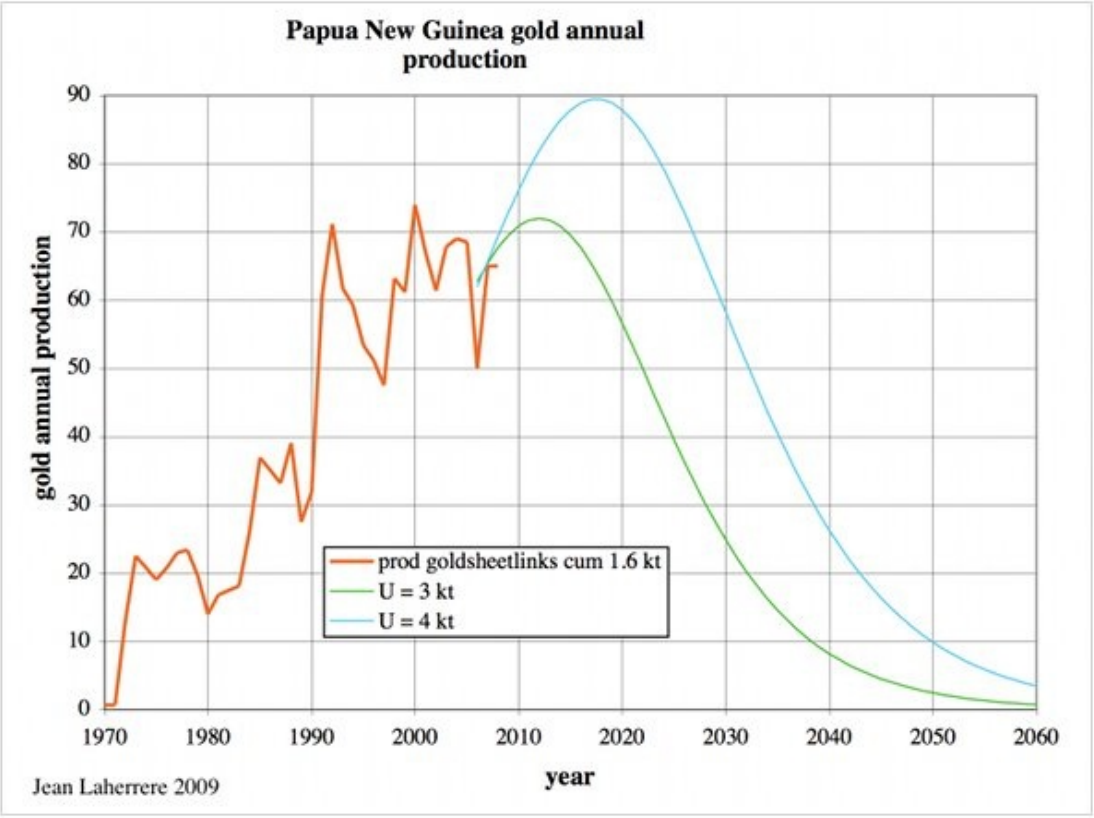

Figure 49: PNG annual gold production and modelling for an ultimate of 3 & 4 kt.

Synthesis of main producers

The data from the above graphs on highest peak and year, annual and cumulative production for 2008 and ultimates are gathered in the following table, and the subtotal of these 14 producers compared to the world figures. These 14 producers sum to 80% of the world's production in 2008 (as cumulative production) and 66% of the world's ultimate value.

Country	Highest peak (t/a)	Peak year	ap** 2008 (t/a)	CP** 2008 (kt)	Ultimate (kt)
S. Africa	1000	1970	234	52	58
Russia	220	1939	174	15	20
US	366	1998	230	17	20
Australia	309	1998	225	12	17
Canada	175	1991	100	10	12
China	288	2008	288	5	9
Indonesia	167	2005	90	1,9	4,5
Uzbekistan	100	1998	85	2,5	4,3
Brazil	105	1980	40	3,4	4
Peru	207	2005	175	2,6	4
Ghana	84	2008	84	1,9	4
Chile	54	2000	42	1	3,5
PNG	74	2000	65	1,6	3,5
Mexico	41	2008	41	0,6	2
subtotal			1873	127	166
World	2600	2001	2356	160	250

* ap = annual production.
** CP = comulative production.

In the following installment, Jean will look at the World's perspectives as a whole.

Previously at TheOilDrum: Peak Minerals.

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