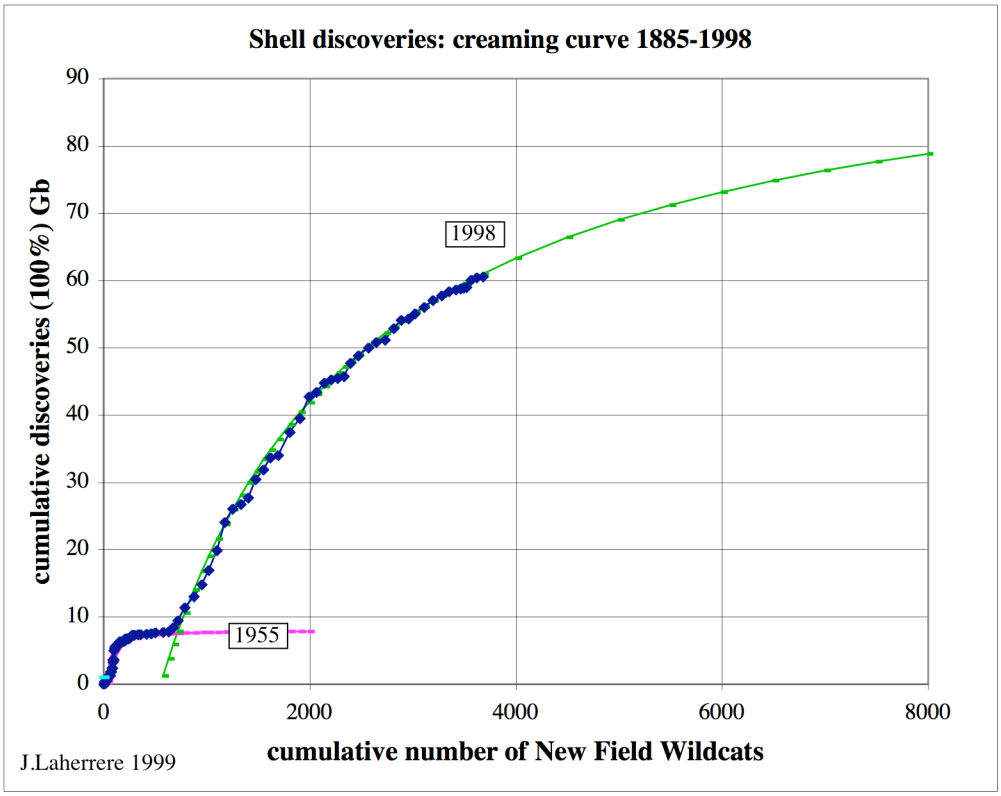
Jean Laherrere March 2009

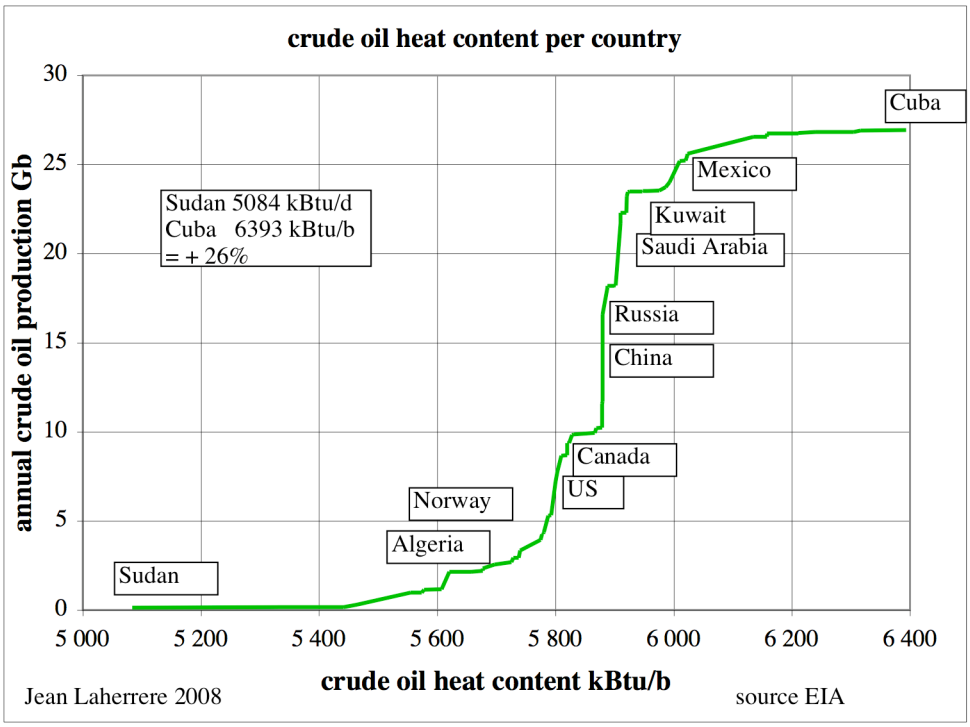
# Creaming curves & cumulative discovery at end 2007 by continents

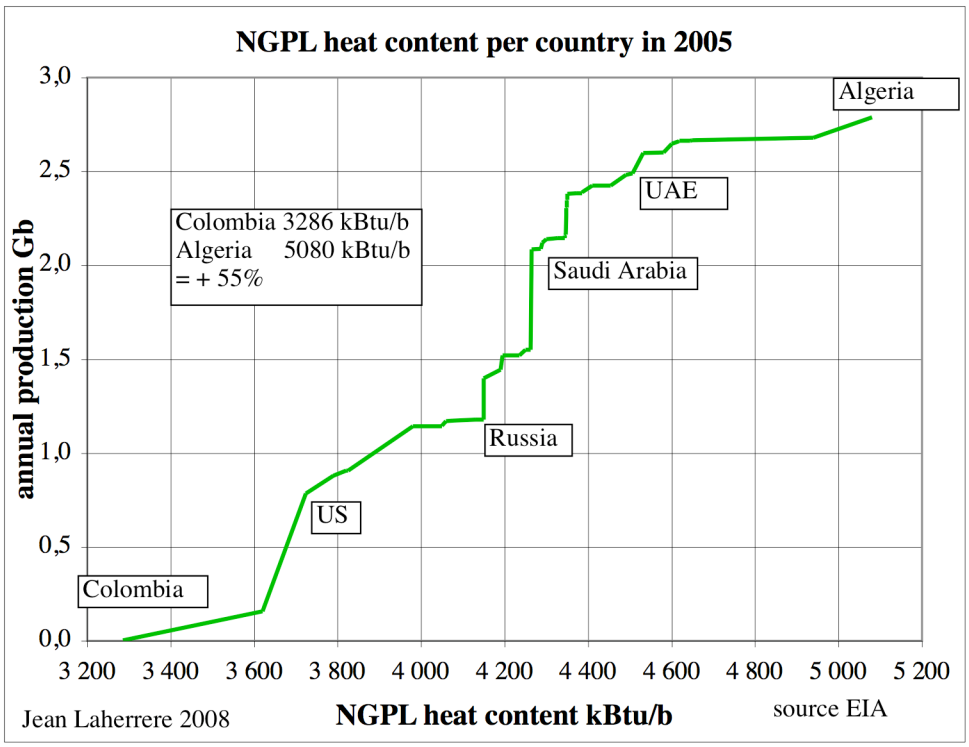
The goal is to estimate the ultimates of the crude oil less extra-heavy oil (Orinoco and Athabasca) and the conventional gas per continent and for the world...
Creaming curve was designed by Shell in the 80s to model the cumulative discovery versus the cumulative number of pure exploratory wells = New Field Wildcat = NFW with hyperbolas.
The plot of Shell discoveries (100% ownership) is beautifully modeled with two hyperbolas. The sharp increase in discovery in 1955 is likely to be due to modern seismic and opening of new areas..




This plot is much better than the cumulative discovery versus time because the stop and goes of exploration. Data on NFW are hard to get and are unreliable in the old past..
Cumulative discovery versus cumulative number of fields can replace the creaming curve but it does not show the change in exploration success ratio.
It is interesting to see that the success ratio (slope of the fields curve) does not change often when a new cycle.

The following graphs is based on IHS at end of 2007, but corrections are applied to obtain the mean backdated value for FSU and Middle East data. Latin America was corrected to remove extra-heavy oil of Orinoco. USDOE and CAPP (Canadian association of petroleum producers) data are used for US and Canada.
Oil and gas discovery are only for conventional reserves, being crude oil less extra-heavy oil whatsoever the location and excluding the continuous type deposits (tight reservoirs). Condensate is added to crude oil, but NGPL (natural gas plant liquids) is a tricky problem. Conventional gas excludes CBM, tight reservoirs and shale gas.
Gas is plotted in Gboe with an equivalence of I Gboe = 6 Tcf
Heat contents vary, the median value is 5.9 MBtu/b for oil, 4.2 MBtu/b for NGPL and 1 Mbtu/cf for gas


crude oil heat content per country
annual crude oil production Gb
30
25
20
15
10
5
0
5 000
5 200
5 400
5 600
5 800
6 000
6 200
6 400
crude oil heat content kBtu/b
Sudan 5084 kBtu/d
Cuba 6393 kBtu/b
= + 26%
Cuba
Mexico
Kuwait
Saudi Arabia
Russia
China
Canada
US
Norway
Algeria
Sudan
Jean Laherrere 2008
source EIA


NGPL heat content per country in 2005
annual production Gb
3,0
2,5
2,0
1,5
1,0
0,5
0,0
3 200
3 400
3 600
3 800
4 000
4 200
4 400
4 600
4 800
5 000
5 200
NGPL heat content kBtu/b
Colombia 3286 kBtu/b
Algeria 5080 kBtu/b
= + 55%
Algeria
UAE
Saudi Arabia
Russia
US
Colombia
Jean Laherrere 2008
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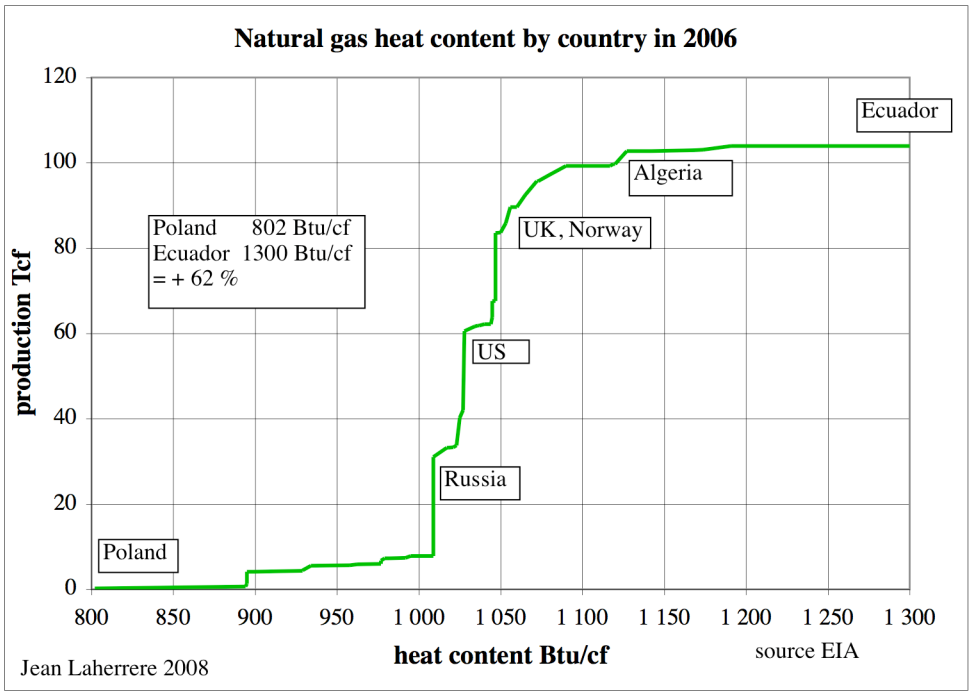
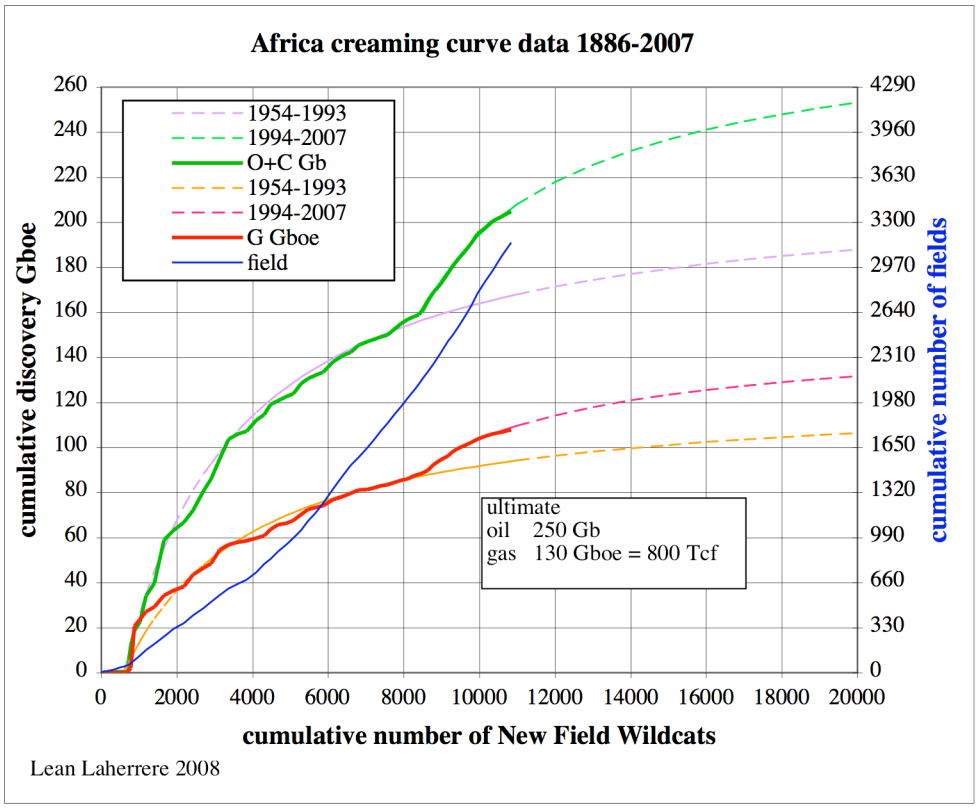


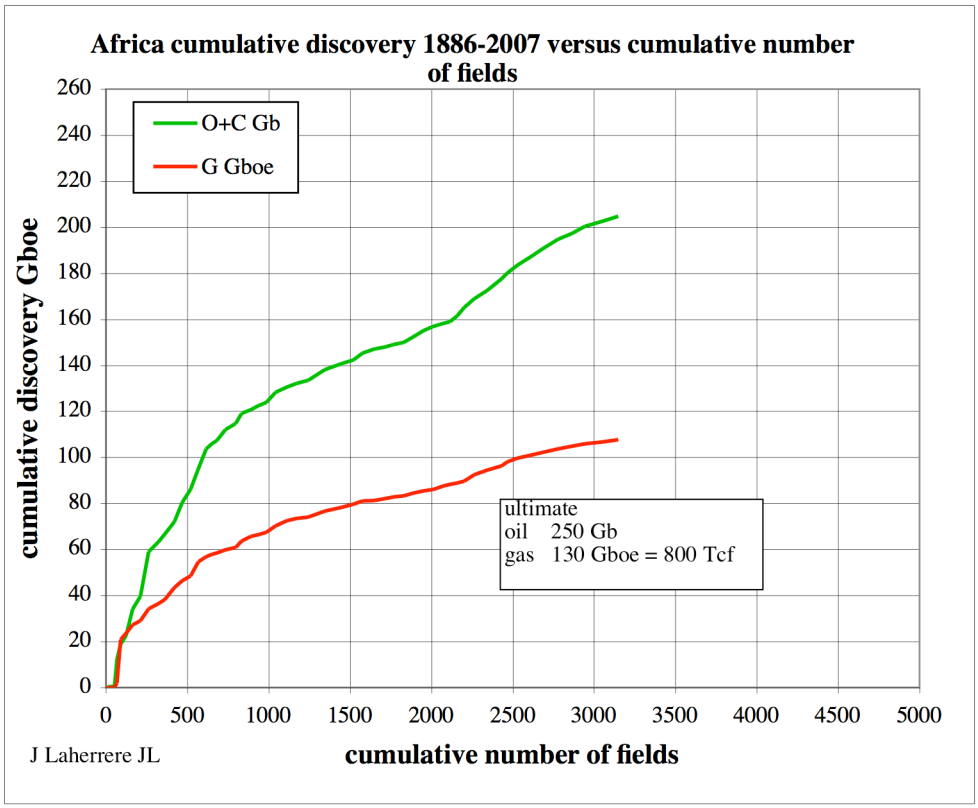

It is amazing how creaming curve can be easily modeled with several hyperbolas. The ultimate is not the sum of hyperbolas asymptotes but the model value for about the double of present NFWs which is assumed to be the end of exploration. The only uncertainty (outside the reliability of present data) is the potential of a new cycle, and it is up to the geologists to guess which new cycle may occur (deepwater?)

**-Africa**

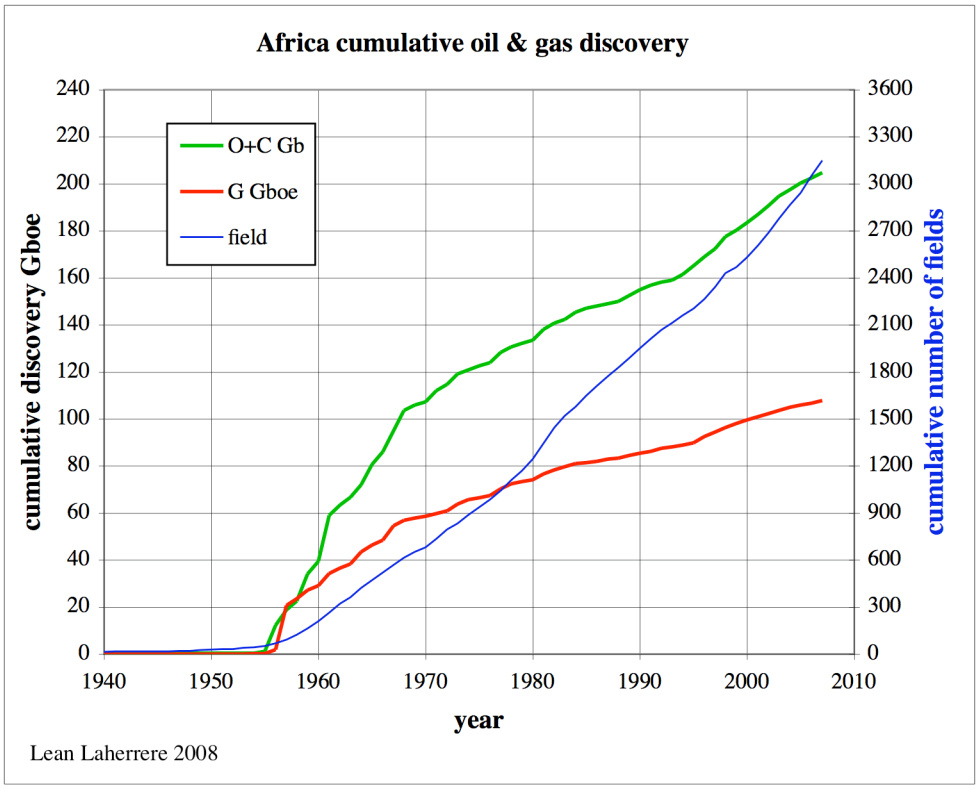
The ultimate from creaming curve modeled with two cycles is 205 Gb for oil and 800 Tcf for gas. When I started plotting Africa creaming curve 15 years ago, only one cycle was present. The second cycle starting in 1994 is mainly due to offshore as Berkine area in the Sahara. The cumulative number of fields trend is not changed by the second cycle.
Is it a third cycle ? Maybe, but it is hard to guess where.




The cumulative discovery versus cumulative number of fields confirms these ultimates

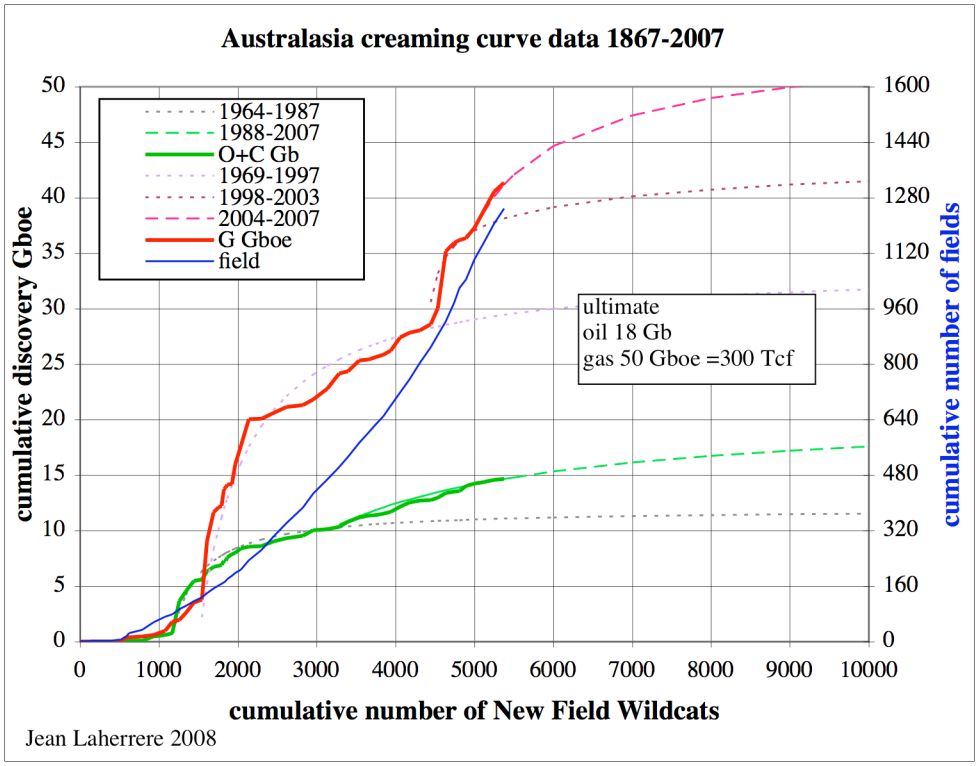



The cumulative discovery versus time shows the change of cycle in 1994




**-Australasia**

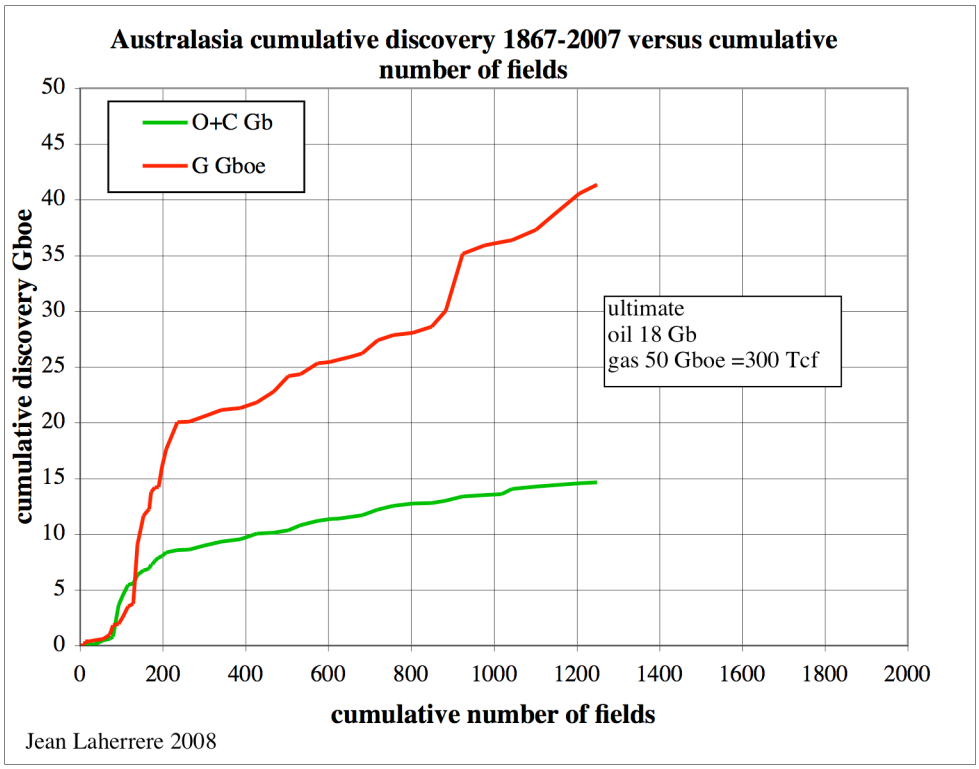
Two cycles for oil and three cycles for gas with ultimates of 50 Gb and 300 Tcf



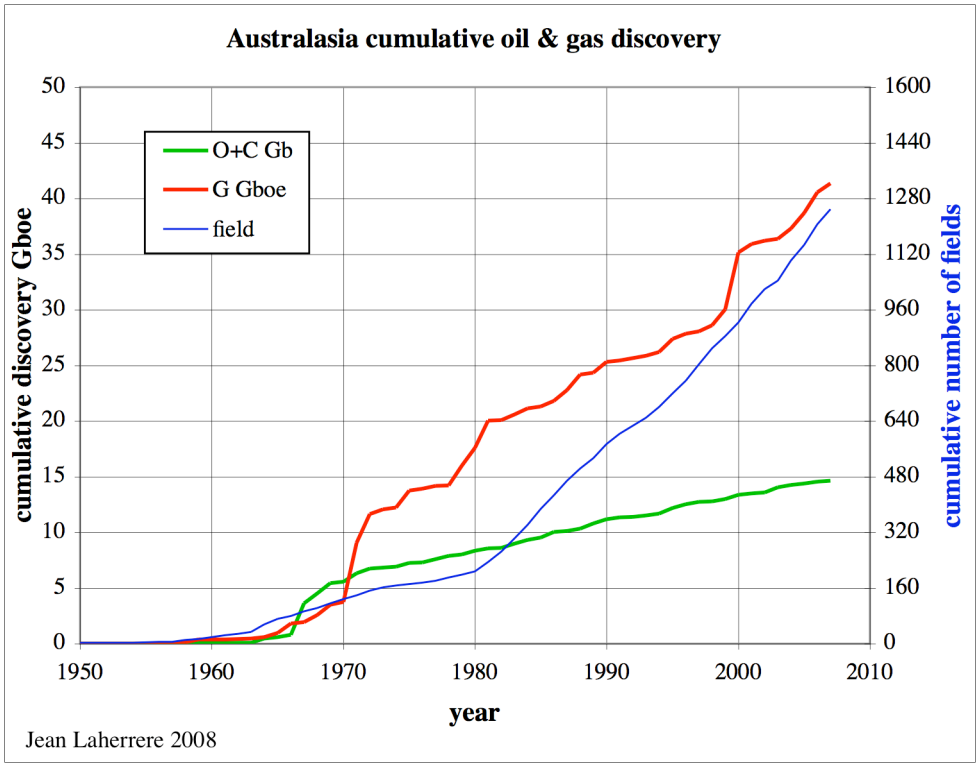

New cycle is possible (deepwater), but with small volume for oil.

Success ratio decreases lately

Cumulative discovery versus cumulative number of fields leads to the same ultimate.



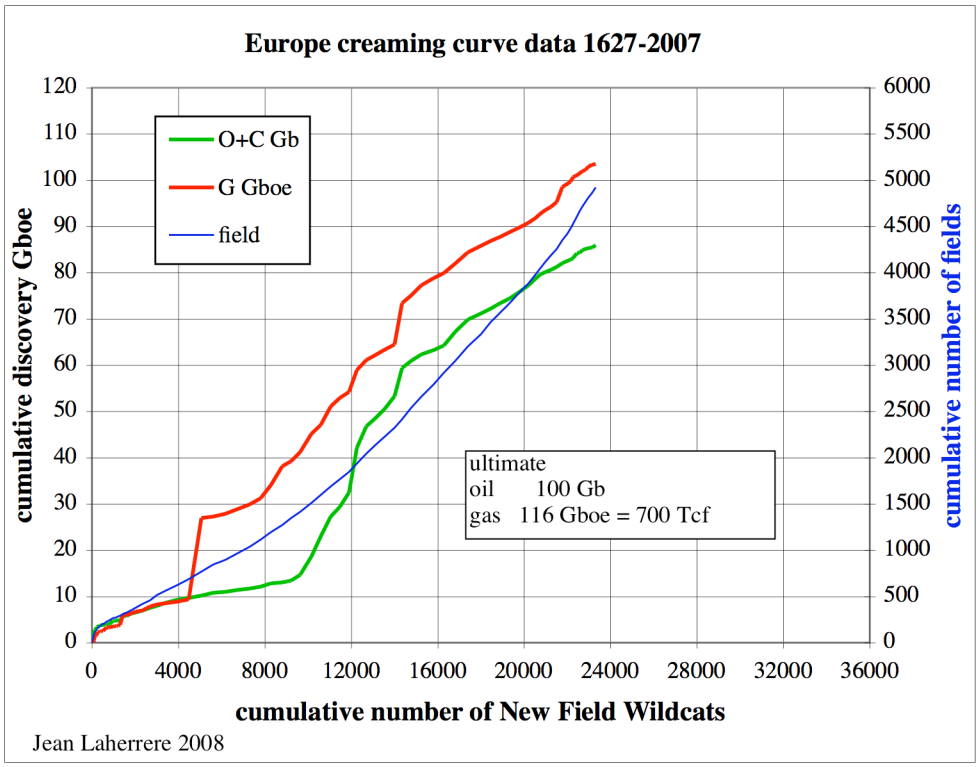

Cumulative discovery versus time displays in 1980 a break in number of fields but not in volume



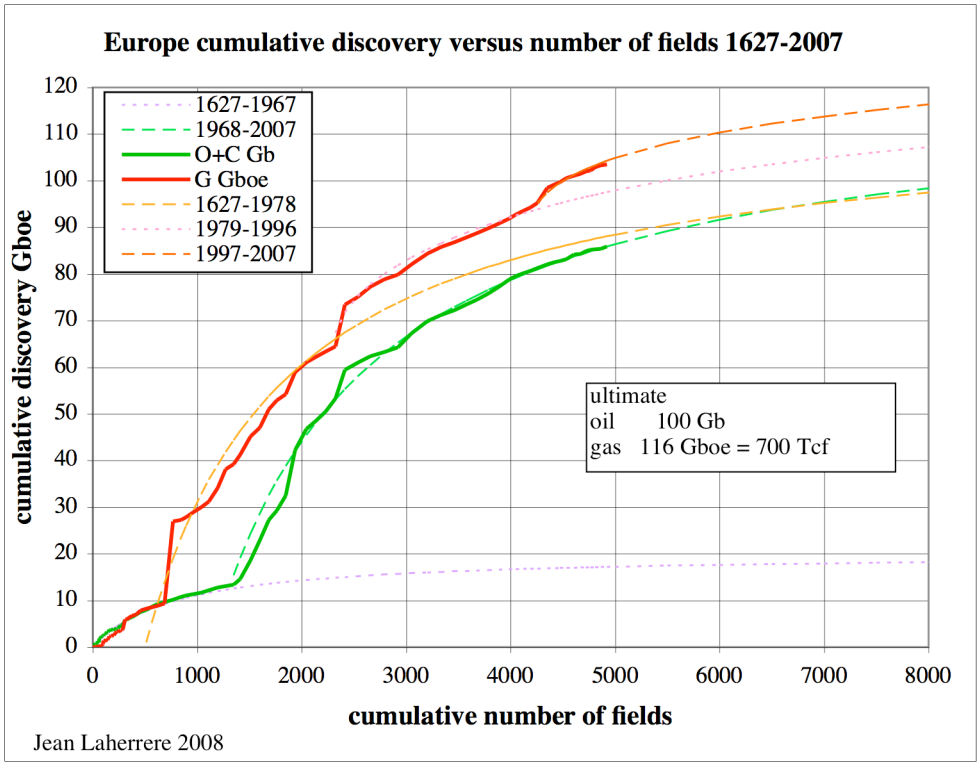

**-Europe**

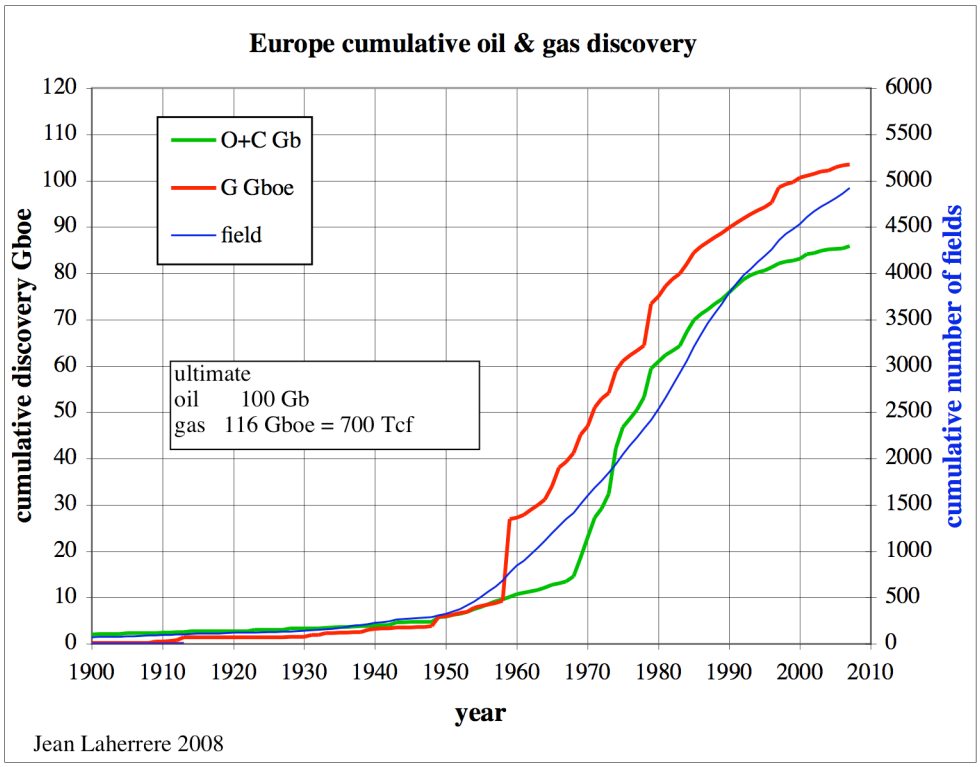
IHS reports in 1627 a field in France = Pechelbronn (where in 1927 the first electric log was run by Schlumberger), but in fact it was more from mine of oilsands. The first pit dug is reported in fact in 1745 (or 1735?) with the first oil company with shares.

The creaming curve is hard to model for gas. The success ratio is increasing (drilling close to discovery searching for small field)s.



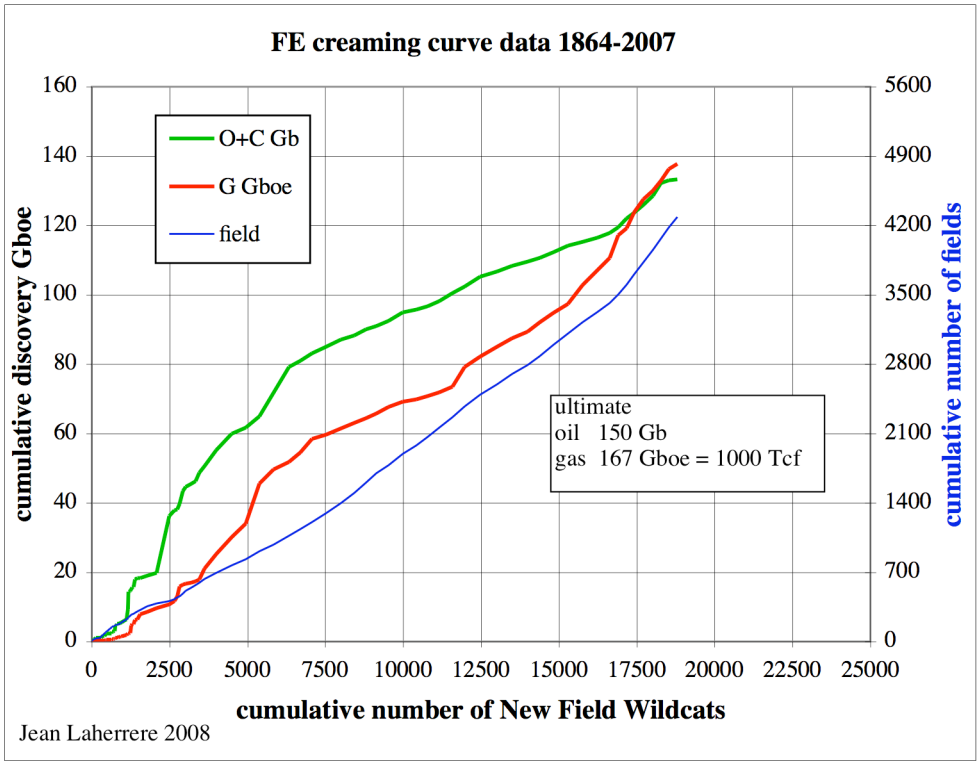

The cumulative discovery versus the cumulative number of fields looks better to model, with two cycles for oil and 3 cycles for gas .
New cycle is likely but of small volume.
The ultimate is estimated at 100 Gb and 700 Tcf



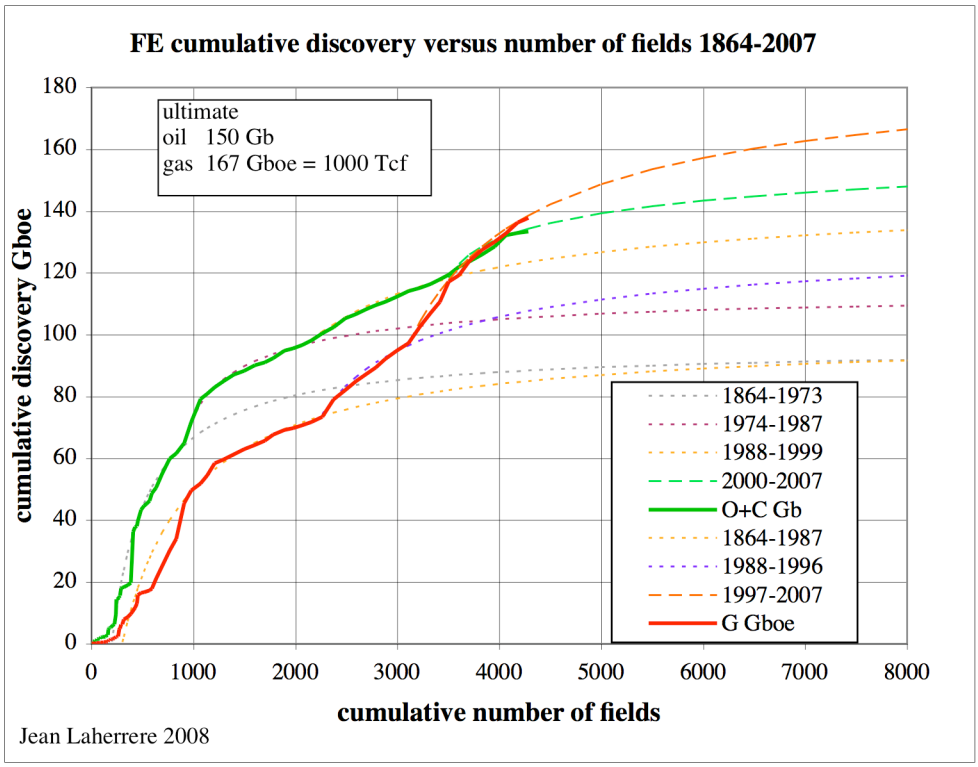


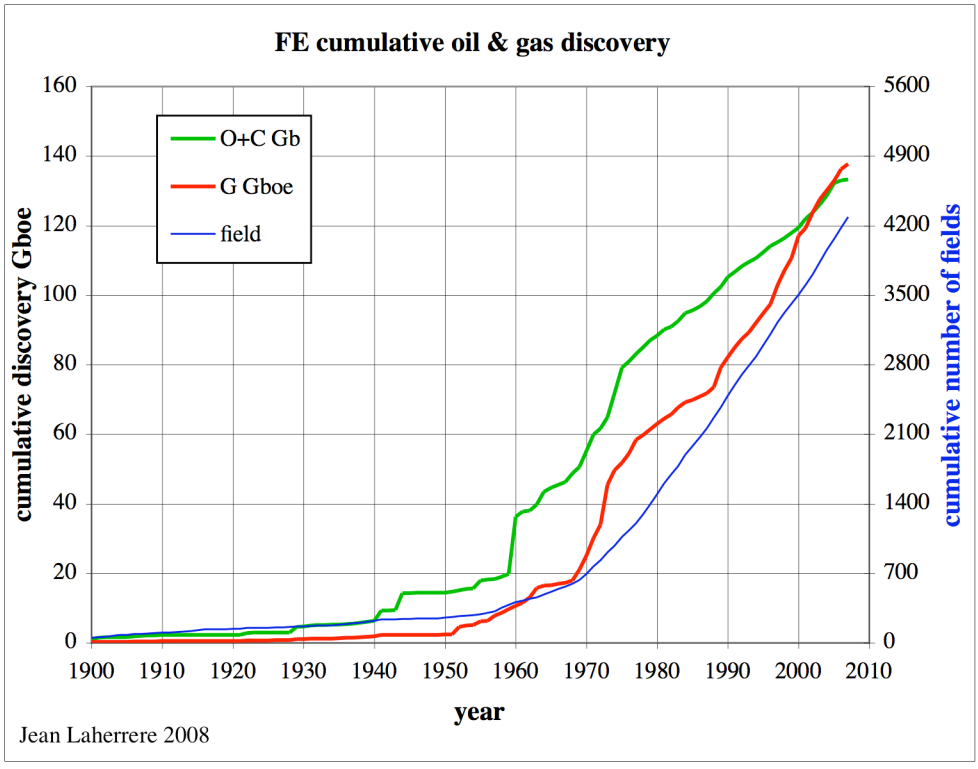

**-Far East**

The creaming curve does not display clear cycles for gas. We found that the reporting of NFWs was messy in China (large revision last year, but incomplete for the recent years). So we prefer to model the cumulative discovery versus the cumulative number of fields.




The cumulative discovery versus the cumulative number of fields is modeled with 4 cycles for oil and 3 for gas with an ultimate of 150 Gb and 1000 Tcf. New cycle is likely but of small importance which will not change the rounded ultimates.

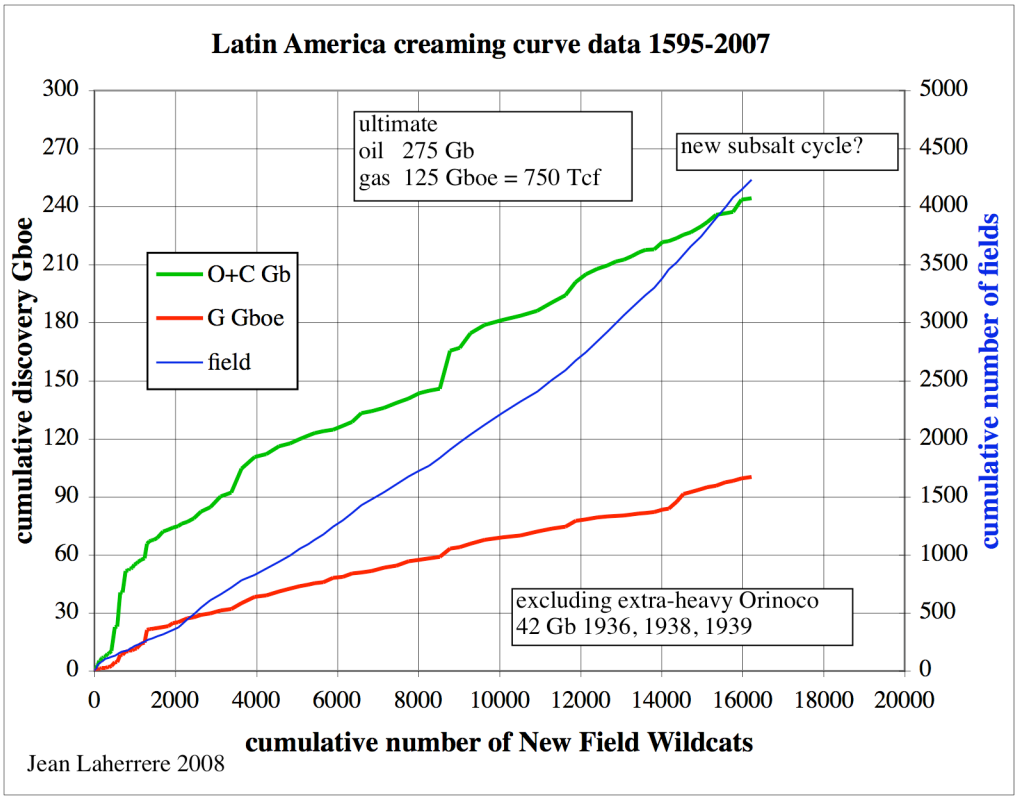


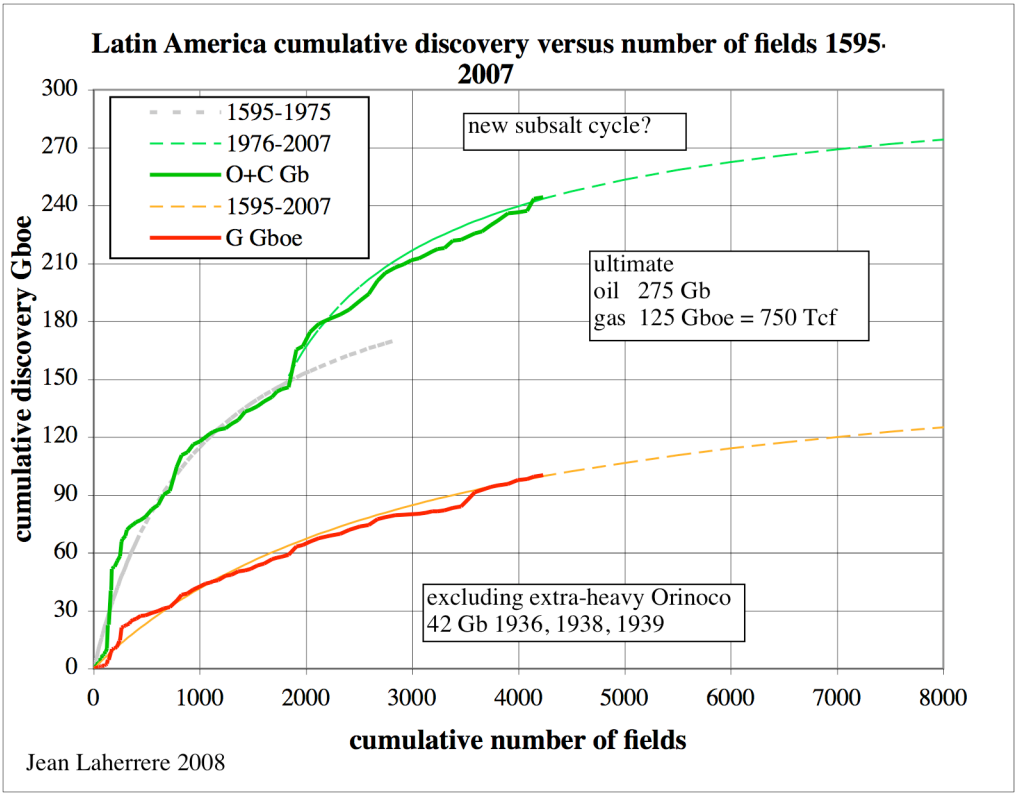

**-Latin America**

Extra-heavy oil of Orinoco (1936, 1938 & 1939 with a total of 42 Gb) has been removed from IHS data in order to stay with crude oil less extra-heavy oil

The creaming curve does not display lately the usual diminishing return, but a linear trend.

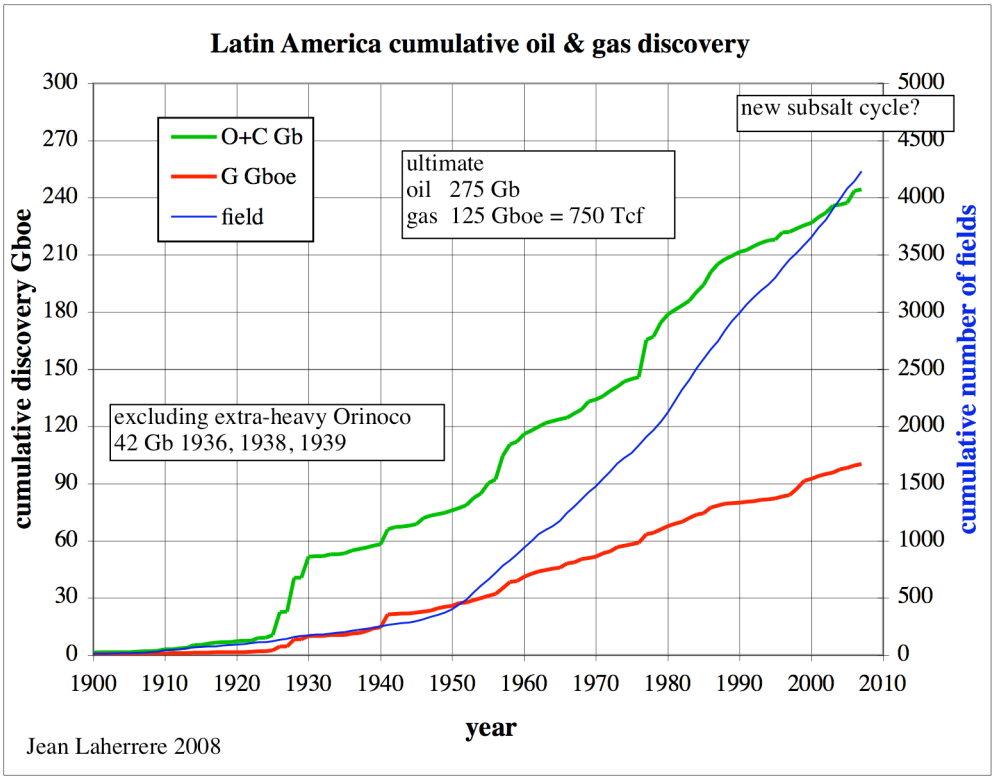



So we model the cumulative discovery versus cumulative number of fields with two cycles for oil and one cycle for gas. The ultimate is 275 Gb and 750 Tcf.
A third cycle with the Brazilian subsalt may occur but up to now the recent discoveries stay within the YTF. Furthermore these discoveries are very deep water, very high pressure and temperature and need to break technological records. In fact this very difficult oil could be treated as unconventional.




The new subsalt discoveries in Brazil is likely to offer a new cycle, but yet-to find being about 25 Gb, there is room and the complexity of these new discoveries may put some in the unconventional side.

The cumulative discovery versus time is difficult to model.

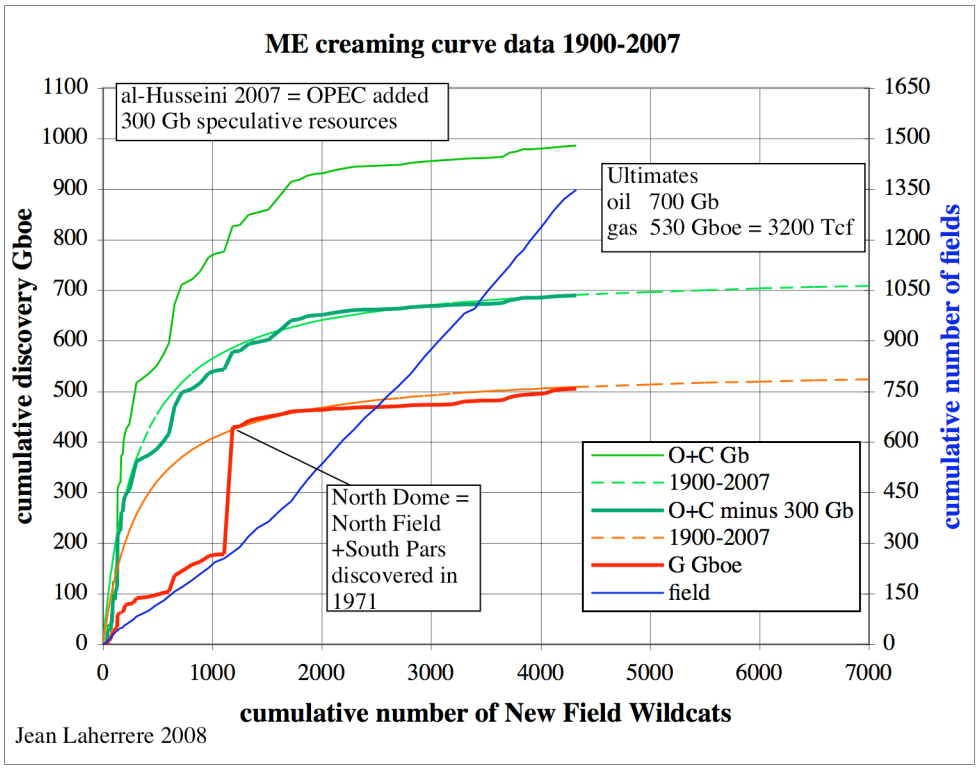



**-Middle East**

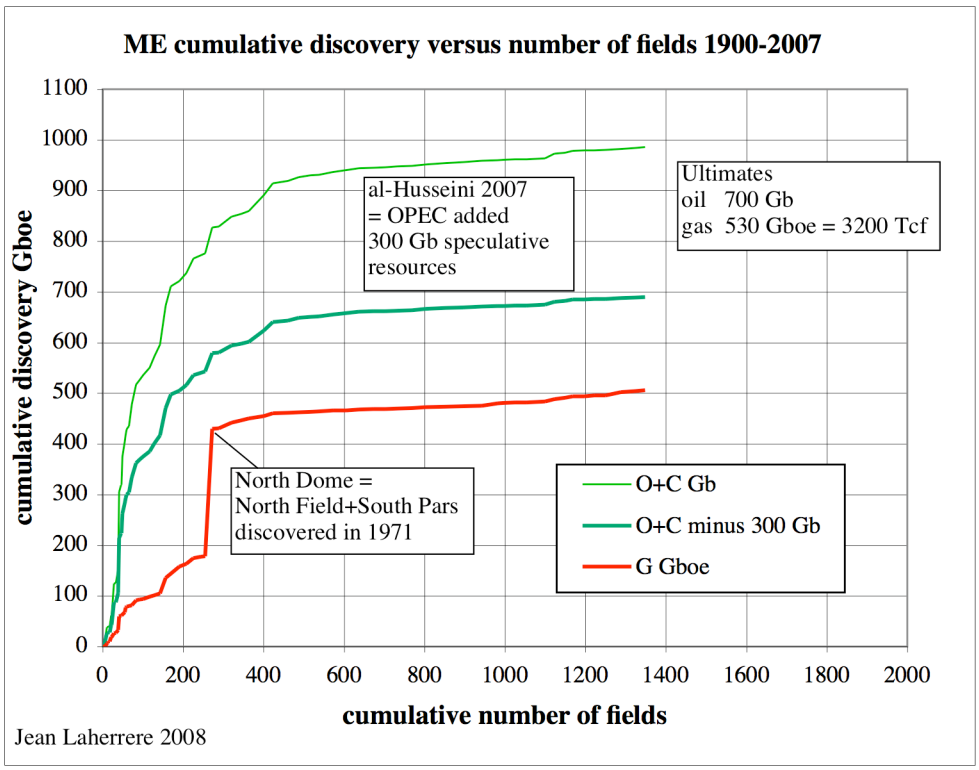
For a long time we (with Colin Campbell) have argued that the 300 Gb increase by OPEC members from 1986 to 1990 (in their fight on quotas after the oil counter shock) was political. In October 2007 in London Sadad al-Husseini (former ARAMCO VP) stated that this 300 Gb were speculative resources. In the past Petroconsultants was estimating field reserves scouting from geologists because no values were released from NOCs, but now IHS is obliged to report the official field estimates and to match NOCs reserves. A correction is necessary, being global and spread on all the exploration period to reduce the reported 1000 Gb to 700 Gb.

The creaming curve is easy to model with one cycle for oil and for gas . The North Dome broken down into North Field in Qatar (drilled in 1971) and South Pars in Iran (drilled in 1991). For years we have corrected the year of discovery of South Pars from 1991 to 1991, because everyone knew that North Field extends into Iran. IHS is now following us and put South Pars discovery in 1971. North Dome represents a large percentage of the world ultimate compared to Ghawar. But present estimates could be optimistic in this carbonate reservoirs (one dry well is rumored in the Iranian side in the middle of the field).

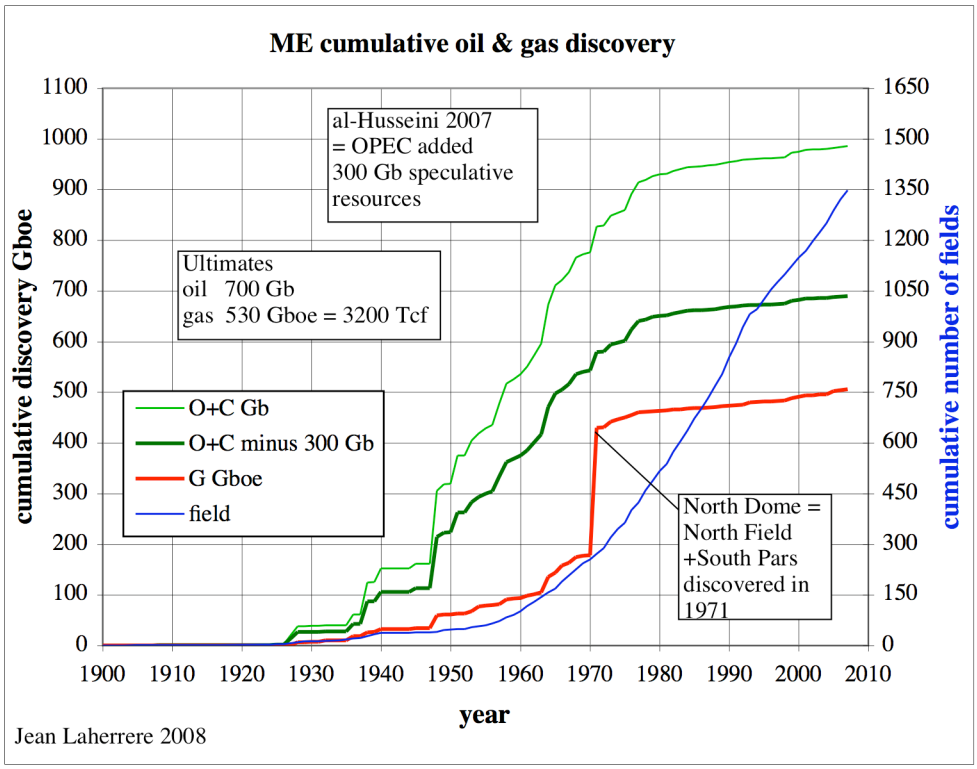
The ultimate is 700 Gb for oil and 3200 Tcf for gas, with very little for yet-to-find. The recent failure in gas exploration in Saudi Arabia confirms this point.. There was claim that Iraq is underexplored with many structures undrilled in the Western desert, but the same al-Husseini was written an article saying that Aramco has explored on the Saudi side and was found almost nothing. There is little chances for a new cycle because there is no deepwater to explore in the Middle East and the creaming curve is almost flat for the last 2000 NFW (half of the total number)




The cumulative discovery versus cumulative number of fields is similar to the creaming curve because the number of NFW is small and well known compared to other continents as Far East.




The cumulative discovery versus time confirms that the added discovery since 1980 is small compared to what was found before despite that the cumulative number of field has grown from 500 fields to 1350 fields. This plot kills the myth that the Middle East is underexplored.



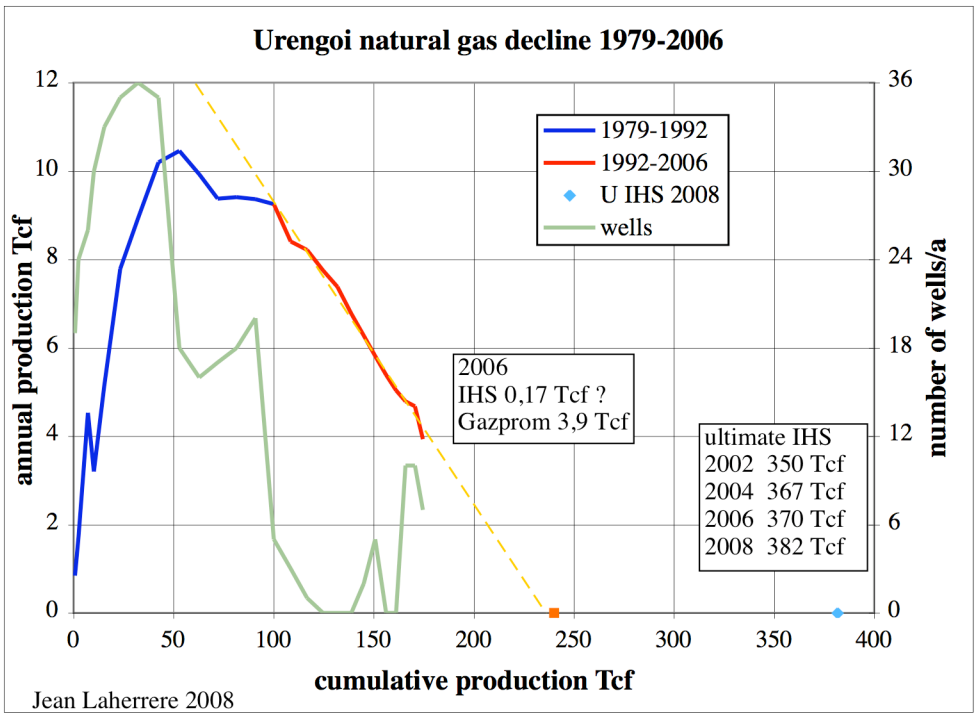

**-FSU or CIS**

Russian classification reporting ABC1 reserves, presented by Khalimov in 1979, was described by the same Khalimov in 1993 as grossly exaggerated, reporting in fact 3P by taking the maximum theoretical recovery factor. In order to reduce ABC1 to 2P a reduction of 30% has to be done. It is confirmed by the decline of fields like Urengoy or Samotlor and by the audit of Gazprom reduced by DGMN from 28 T.m3 to 20 T.m3.

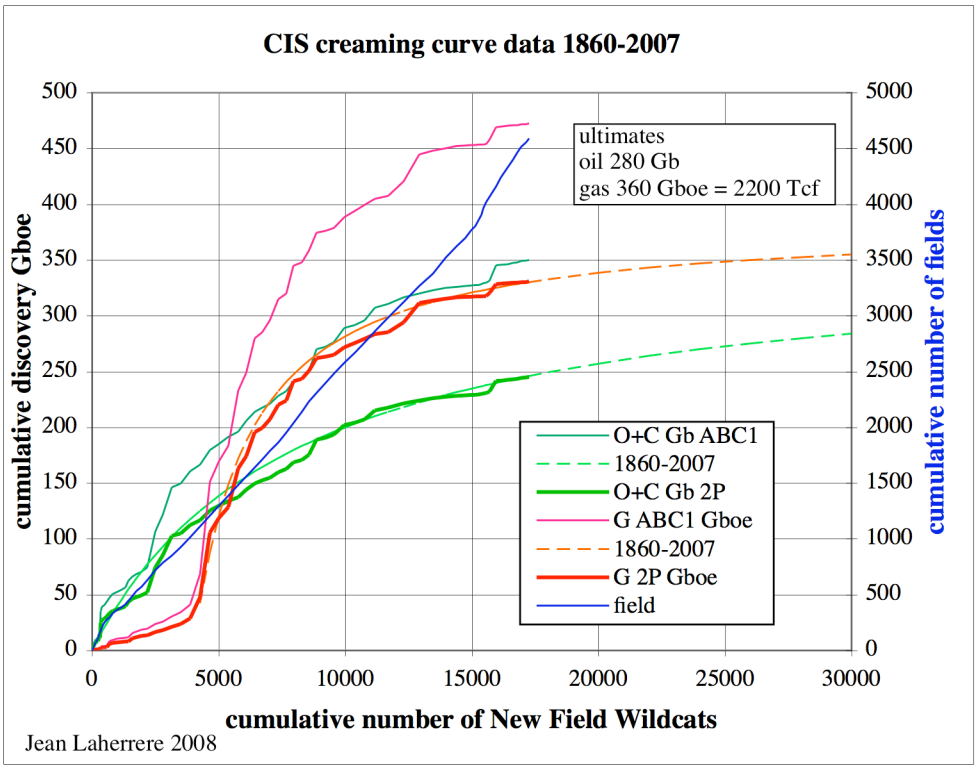
The creaming curve is easily modeled with one cycle for oil and two for gas.

The ultimates is 280 Gb and 2200 Tcf.

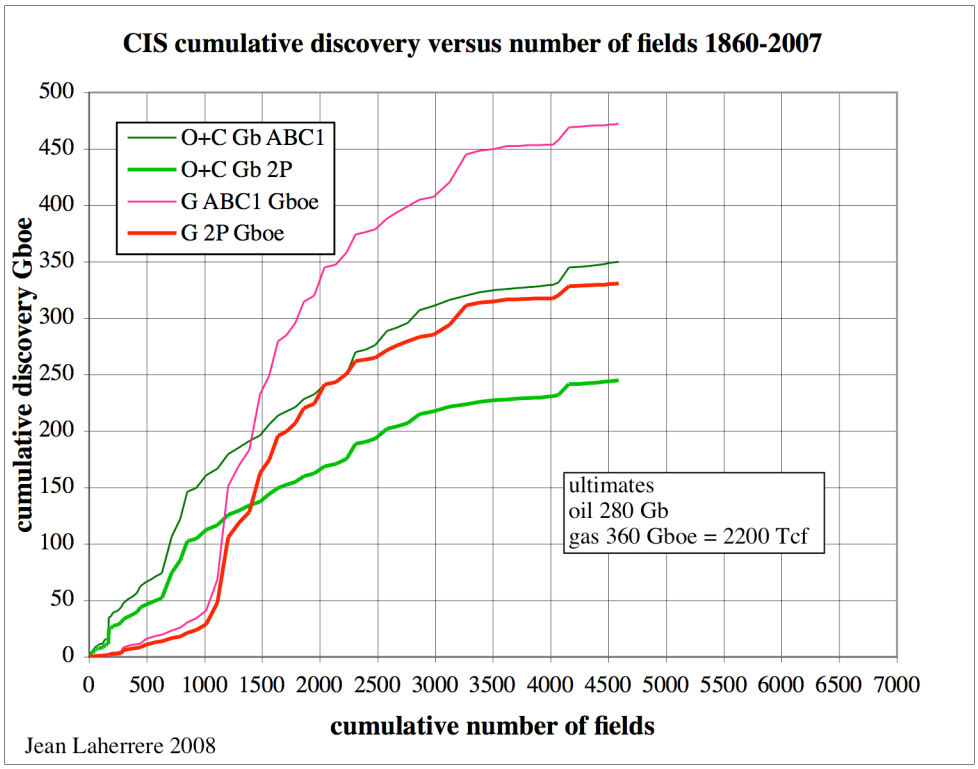
The potential of a new cycle is there despite the flattening of the creaming curve, but the big uncertainty is on reserves values, mainly after the press release in October 2008 that an audit by Gaffney, Cline & Ass of the Turkmenistan gas fields has increased the reserves of Yoloten Gunorta (discovered in 1971 and reported 1,3 Tcf) and Osman (found in 2007 and reported at <1 Tcf) was appraised with 12 new wells and both fields is now a very large field South Yolotan with reserves from 4 to 14 T.m3 ( 2P = 6 T.m3 = 212 Tcf) which is about the same as Urengoi (reported as 382 Tcf in 2008 with a unreliable production value in 2006 but decline is tending to 240 Tcf).



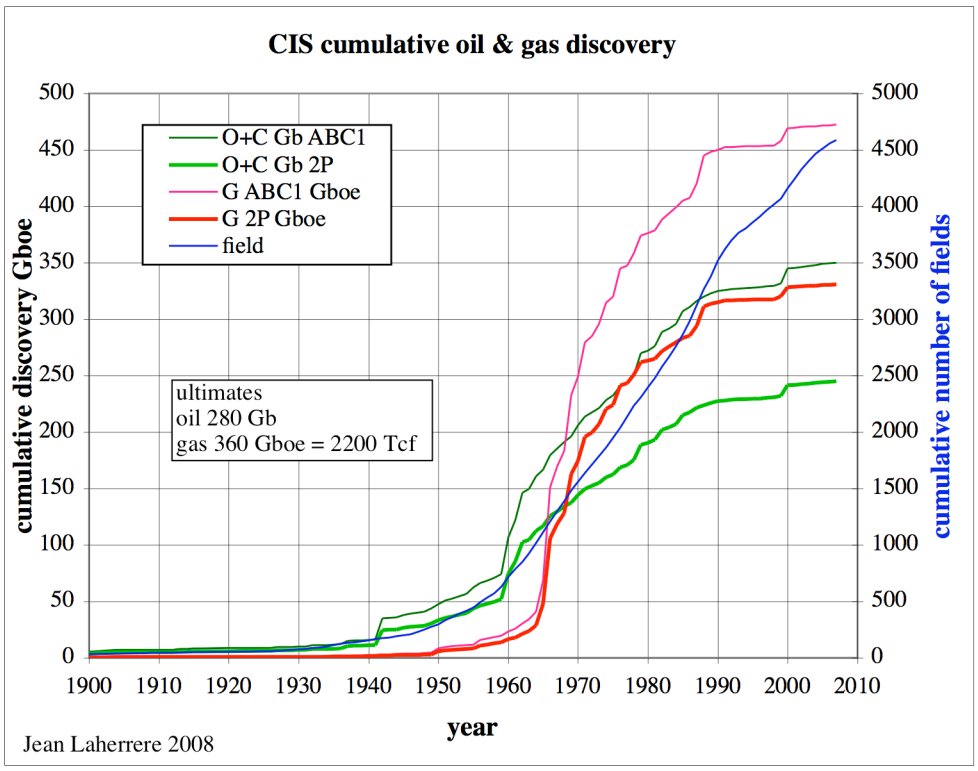

I have increased Turkmenistan gas ultimate from 3,5 T.m3 to 10 T.m3 in a recent paper:
-Laherrere J.H. 2008 « Forecasting world oil and gas production under strong economic constraints » Club de Nice NICE Energy & Geopolitics 7th Energy & Geopolitics Forum Energy relations between Europe and Russia: from difficult dialogue to vital partnership 12-14 November http://www.iehei.org/Club_de_Nice/2008/Jean_Laherrere.pdf, aspofrance.viabloga.com/files/JL_Nice08_long.pdf
If the estimate is right I have to increase Turkmenistan and CIS by at least 200 Tcf.
But this audit is still confidential.




The cumulative discovery versus cumulative number of fields is similar to the creaming curve, confirming that recent discoveries did not bring much reserves.

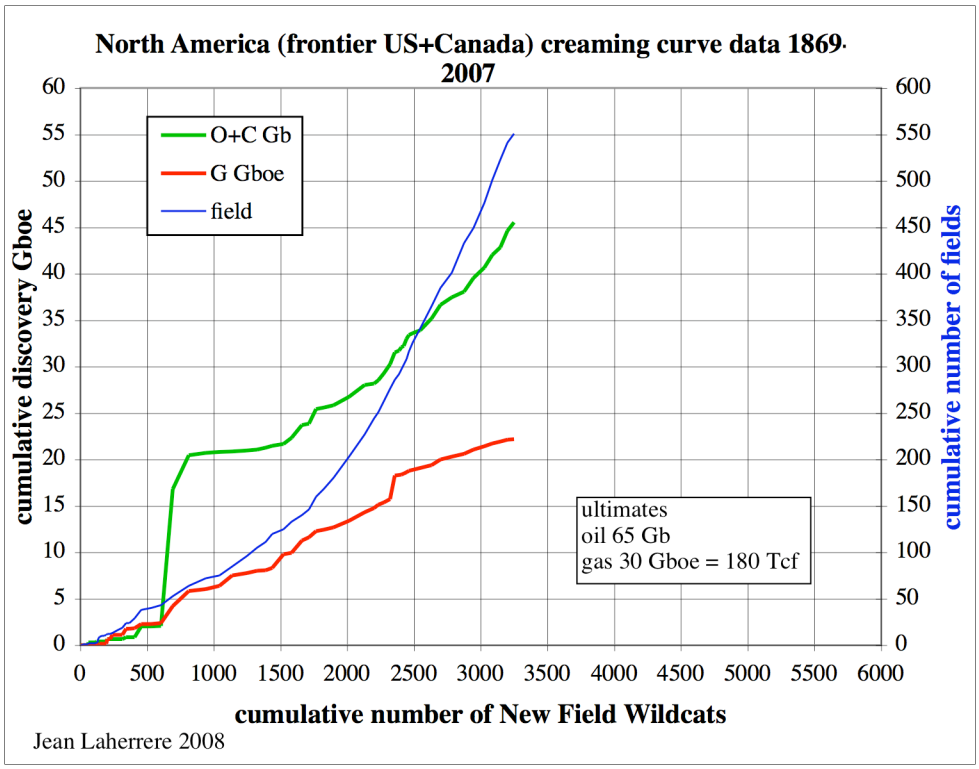



The cumulative discovery versus time confirms the flattening but the data need to be audited in order to avoid increase  like in Turkmenistan. The big problem is that gas exploration is blocked by the monopoly of Gazprom in gas pipelines, and Gazprom is short of money (Bovanenko 1978 discovery larger than Shtokman is still undeveloped and obliged for political reasons to invest in countries as Bolivia!.

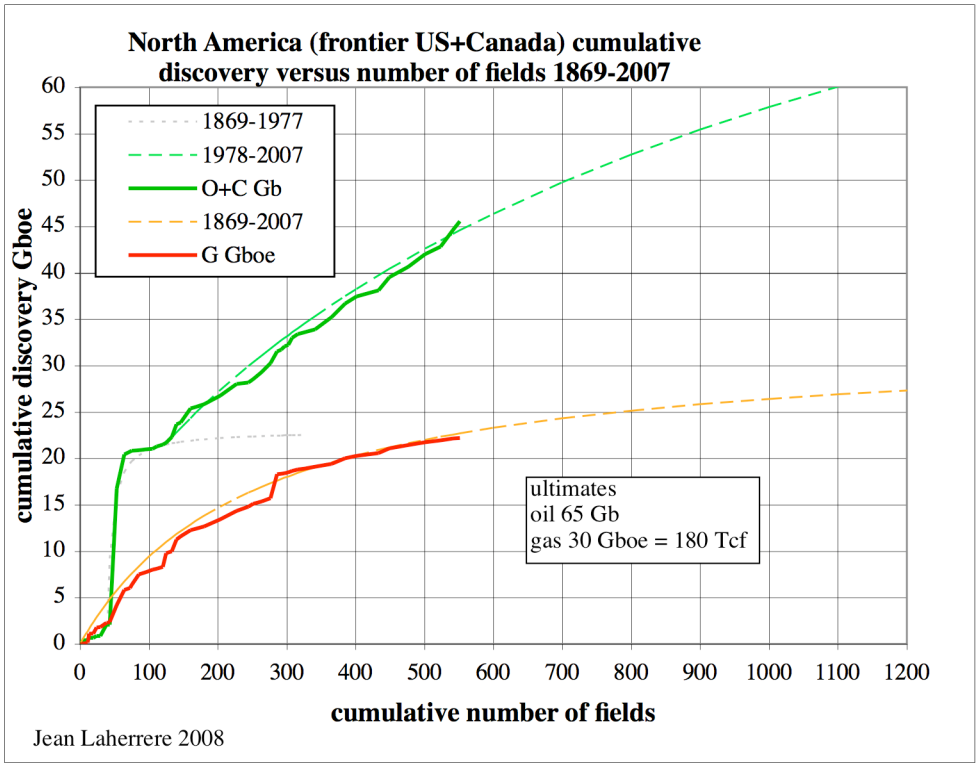



**-North America = US +Canada**
**-IHS frontier data**

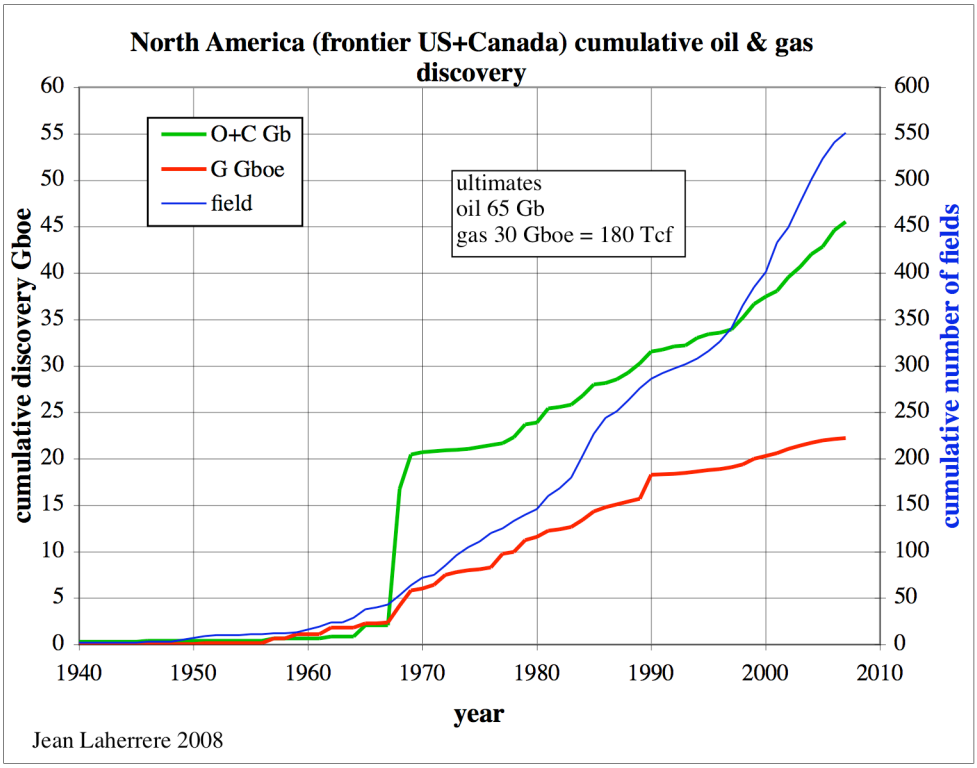
IHS EDIN reports only frontier areas US+ Canada, excluding the very large number of fields inside the US onshore as the WCSB (Western Canadian sedimentary basin)
The creaming curve is difficult to model for oil with the curve increasing sharply but easier for gas.




The cumulative discovery versus cumulative number of fields is modeled with two cycles for oil and one cycle for gas. The ultimates are 65 Gb for oil and 180 Tcf for gas.



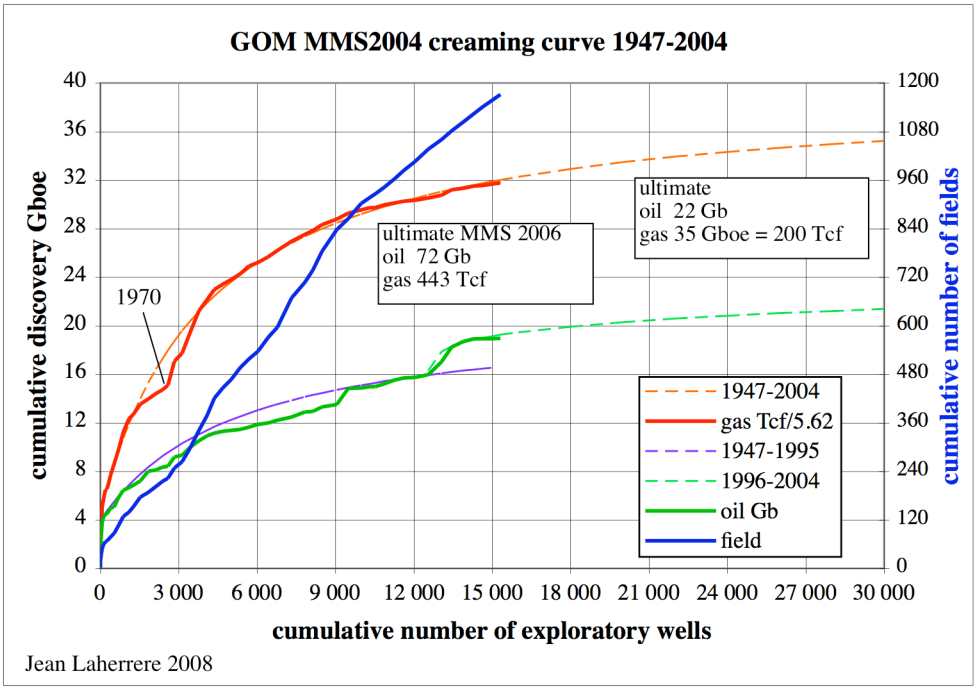

The cumulative discovery versus time indicates that the oil discovery did increase since 1997 with deepwater.



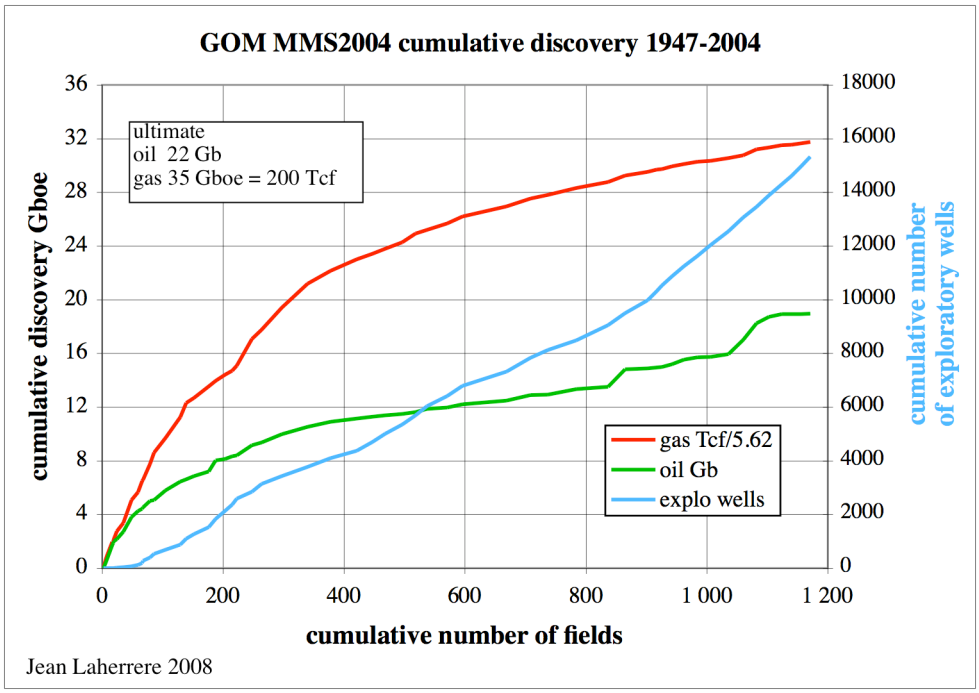

**-MMS data on Gulf of Mexico**

MMS (Mineral Management Services with US DOI) provides a very detailed database but unfortunately with a lag (presently only 2004 data is available)

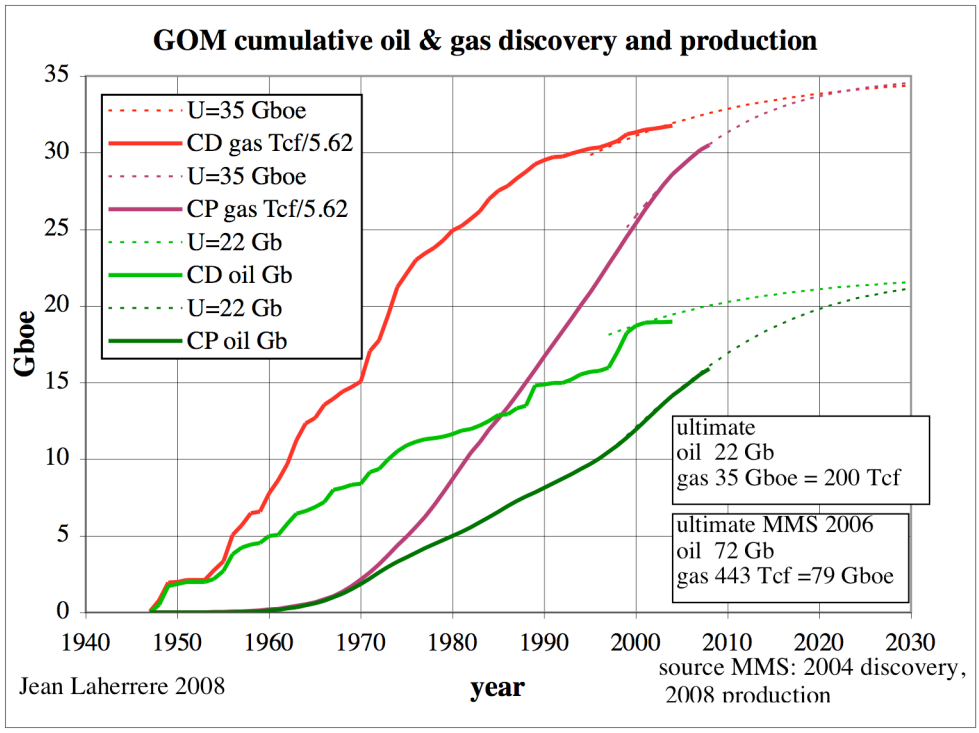
The ultimate from the creaming curve is 22 Gb for oil and 200 Tcf for gas to be compared to MMS ultimates at 72 Gb for oil and 443 Tcf for gas.




The cumulative discovery versus cumulative number of fields agrees with the creaming curve.



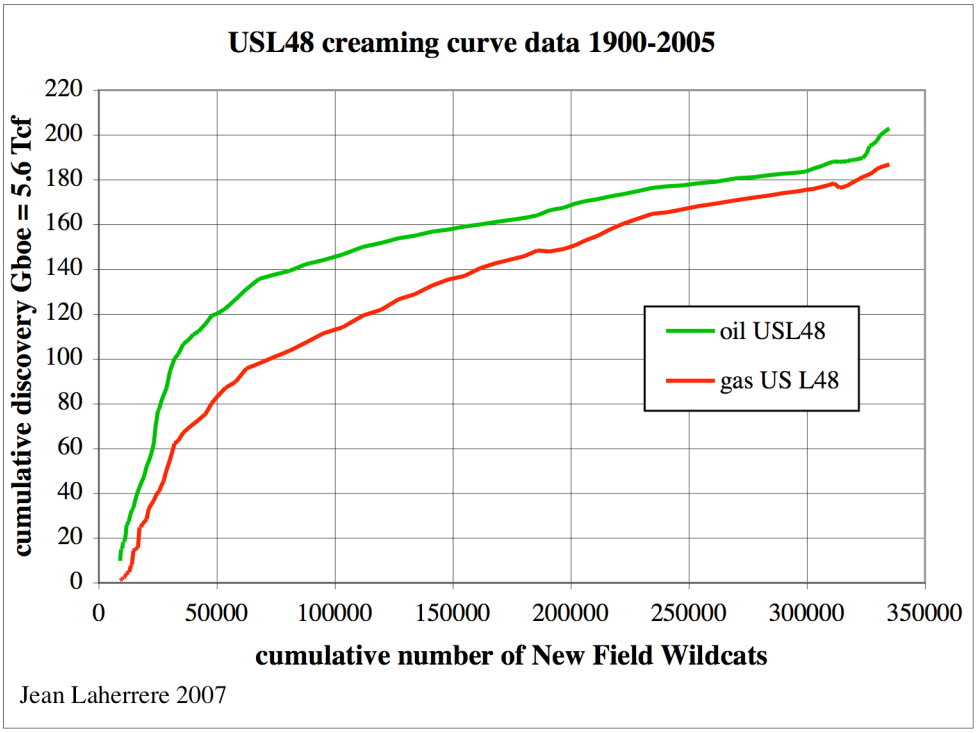

The cumulative discovery versus time is modeled with a logistic curve for the ultimates of 22 Gb for oil and 35 Gboe+200 Tcf for gas. The cumulative production is modeled with the same ultimate. MMS provides the annual production for 2005 to 2008 and these values are plotted on the model and it fits perfectly. Meaning that the MMS ultimates of 72 Gb and 443 Tcf will fit with difficulty with the present production data.



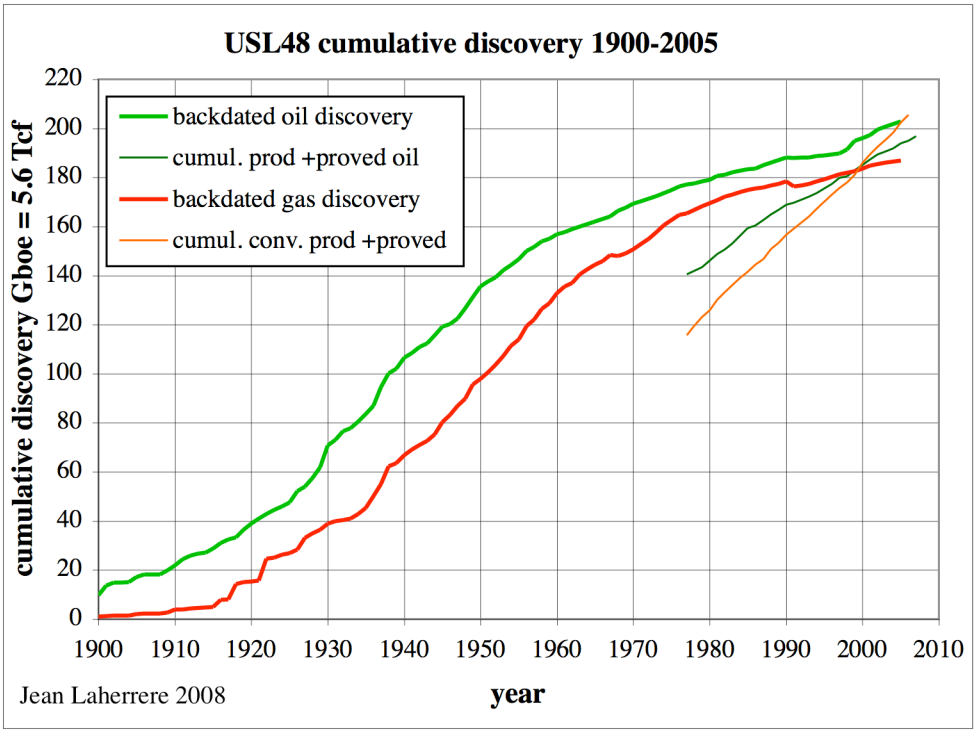

**-US Lower 48**

USDOE/EIA has published in 1990 a report USDOE/EIA-0534 1990 "US oil and gas reserves by year of field discovery" Aug. Open file which provide the backdated estimated annual discovery. This 1990 open file is unavailable on USDOE site: I guess that USDOE does not want to update it and prefers to ignore it.

The EIA annual reports since 1990 reports new discoveries which were used to complete the previous data. It is a pity that the EIA (who has the data) is not updating the important 1990 report on reserves by year of discovery..

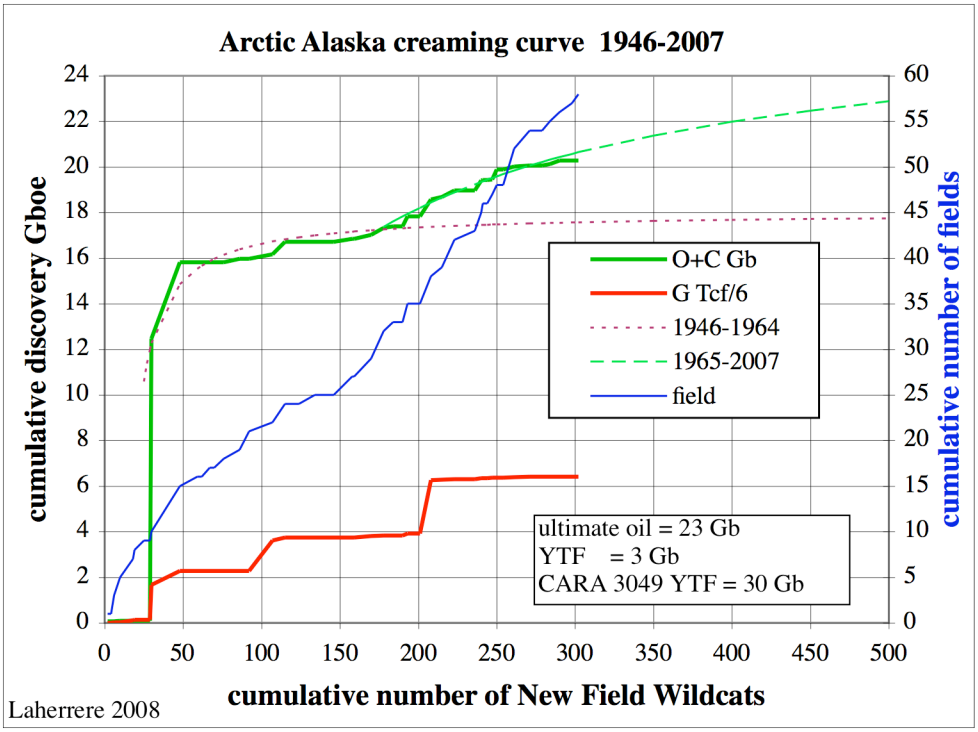



The same cumulative backdated discovery versus time shows the flattening of discovery but with a slight improvement with recent deepwater.
The current proved reserves added to the cumulative production displays a completely different trends, showing that proved reserves are useless for forecasting the future.

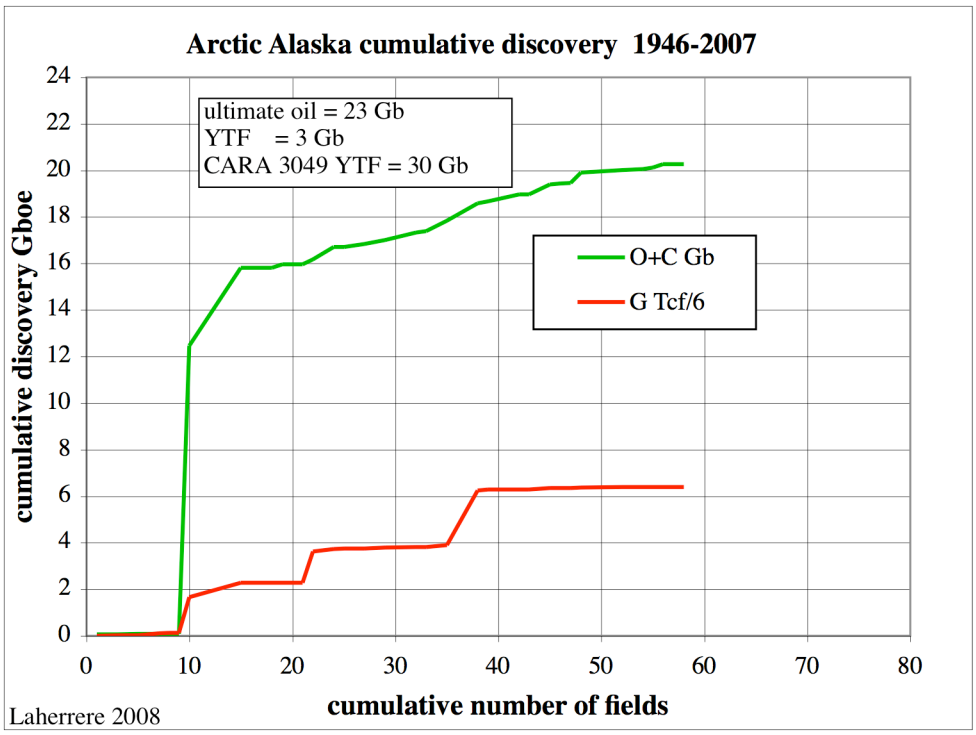



**-Alaska**
The creaming curve is easy to model with two cycles. Natural gas is stranded in the North Slope and the exploration did not look for it. The oil ultimate is estimated at 23 Gb with YTF being only 3

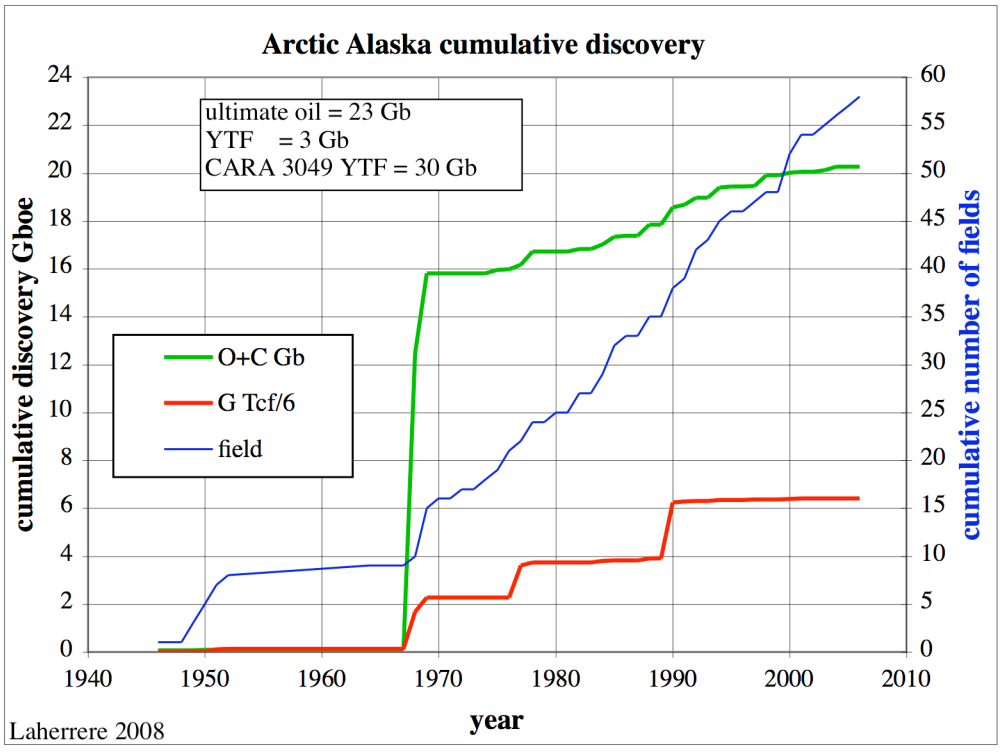
Gb. The recent success ratio is high but discovery small. I do not see where to get a new cycle. There is great hopes on the ANWR, claiming that it was undrilled but a well was drilled on it, called Kic in 1985, still confidential, but rumored to be dry. The nearest field Badami was developed at great expenses by BP believing that the reserves were 120 Mb (despite negative pressure information), but it was abandoned few years later after a production of only 5 Mb. Only politicians want to explore the ANWR but not the oil companies with the data.
USGS 2008 CARA 3049 report estimates the YTF in Alaska at 30 Gb: 10 times more than me, believing in particular that the Chukchi has a great oil potential (following MMS estimate), but it was explored late 80s-early 90s with 4 dry holes and only I gas discovery (2-10 Tcf for MMS deemed not commercial, 14 Tcf for IHS) which was abandoned by Shell. But Shell bought this field again in last year sale for 100 M$, which is less that the cost of a well in this very expensive frozen offshore. Paul Nadeau with Statoil stated (IGC 33 in Oslo) on the USGS report on Arctic (Daily News N°6 August 12, 2008 : Vast resources of petroleum-hopefully) : « their numbers are too high »




The cumulative discovery versus cumulative number of wells is similar to the creaming curve, because the success ratio does not change much around 20%

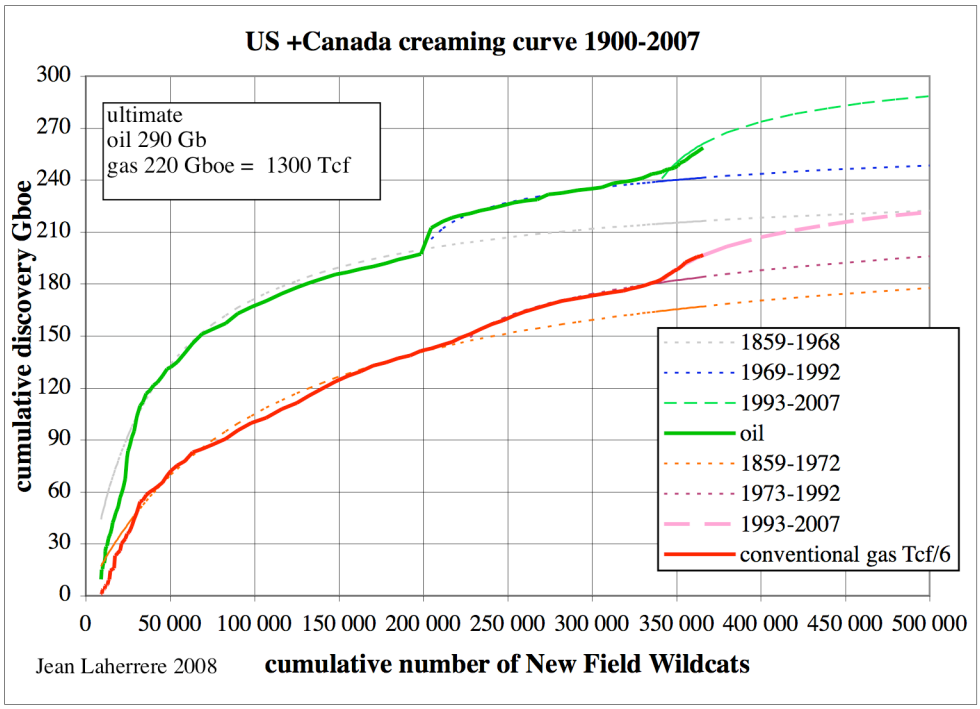



The cumulative discovery versus time confirms the flattening of the curves (flat for gas) despite continuous discoveries.

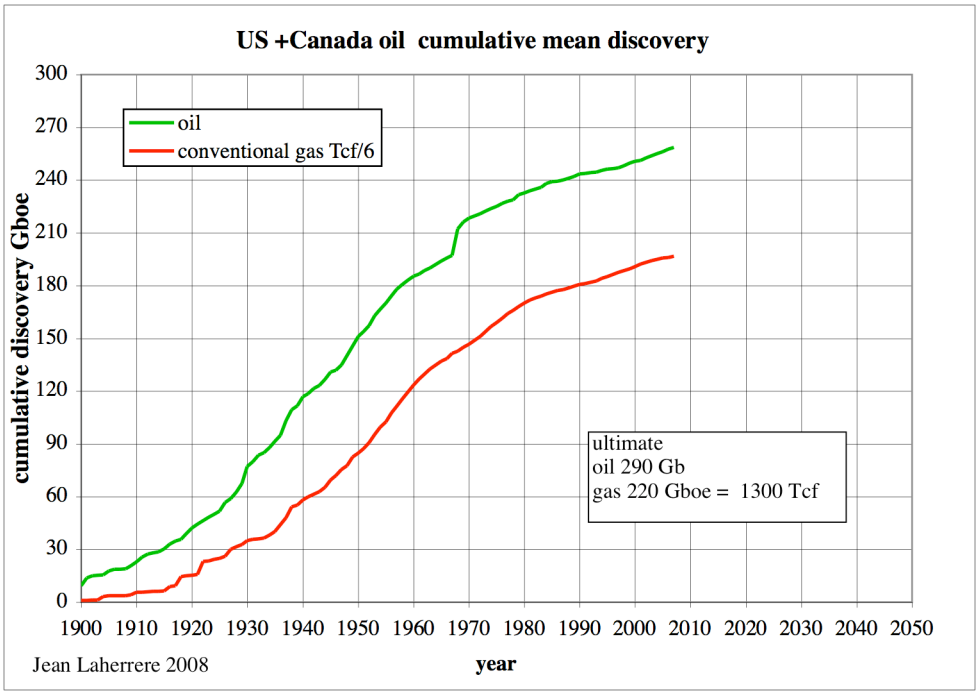



**-US+Canada**

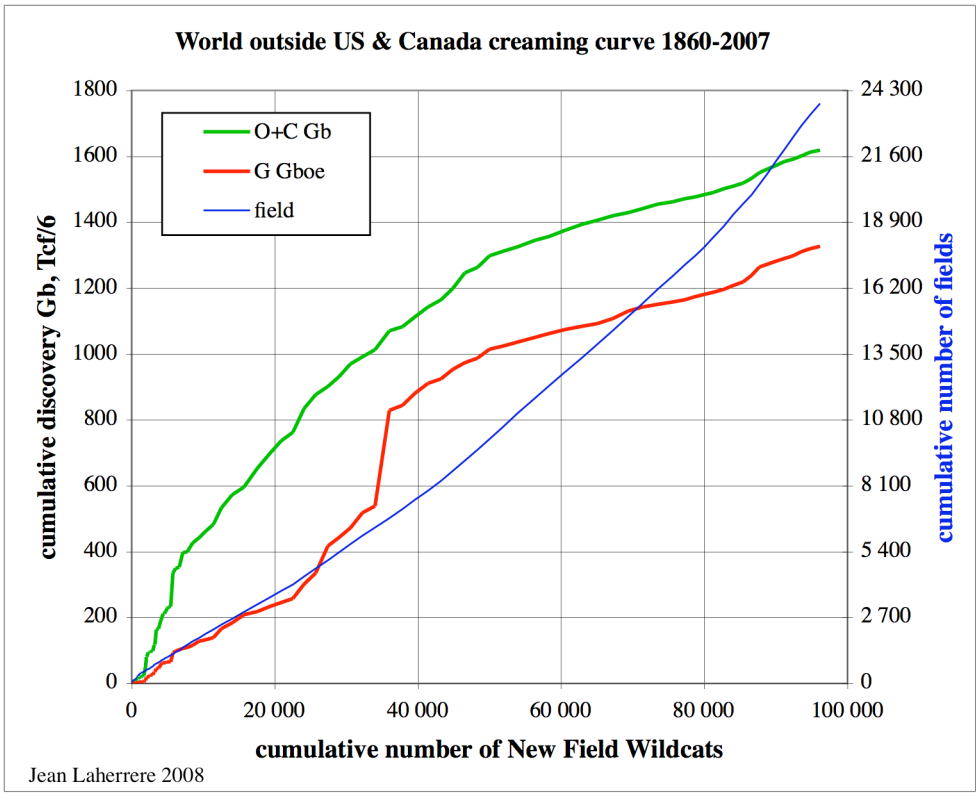
Adding the US L48 complete data from Attanasi E.D. & Root D.H. 1994 "The enigma of oil and gas field growth" AAPG 78/3 March, table 1 and from USDOE/EIA-0534 1990 "US oil and gas reserves by year of field discovery" Aug. Open file with the CAPP handbook annual backdated discovery, the creaming curve can be modeled with 3 cycles giving an ultimate of 290 Gb for oil and 220 Gboe=1300 Tcf for gas



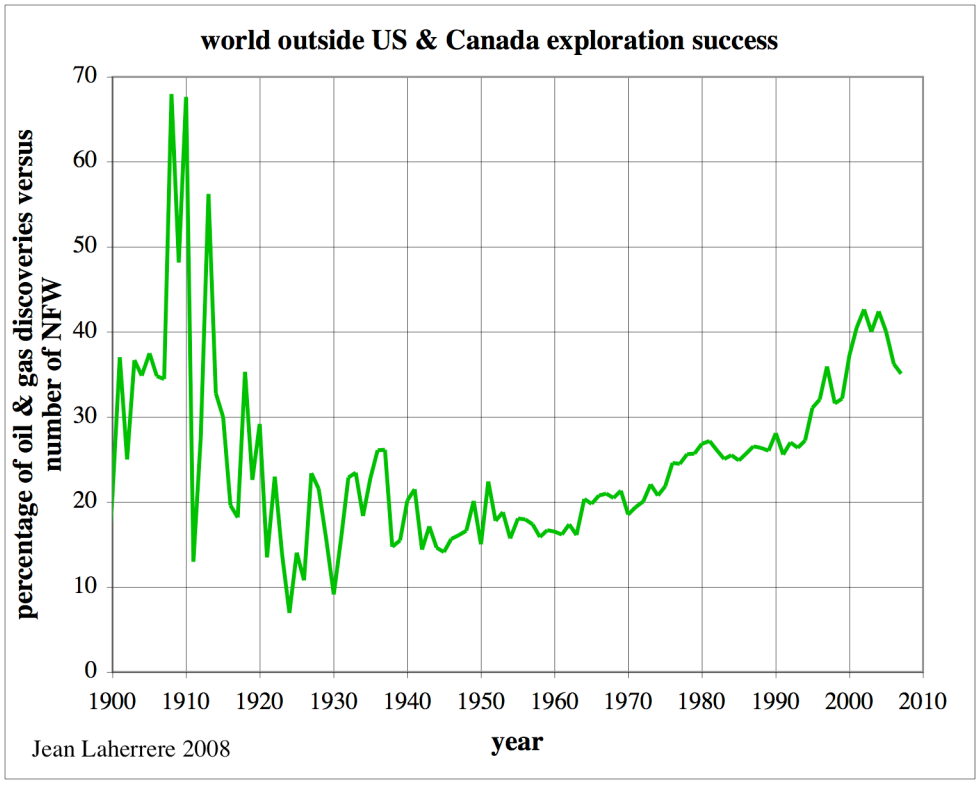

I was unable to plot the cumulative discovery versus the cumulative number of fields because Canadian file reports only pools and not fields.
The cumulative discovery versus time is close to a logistic curve



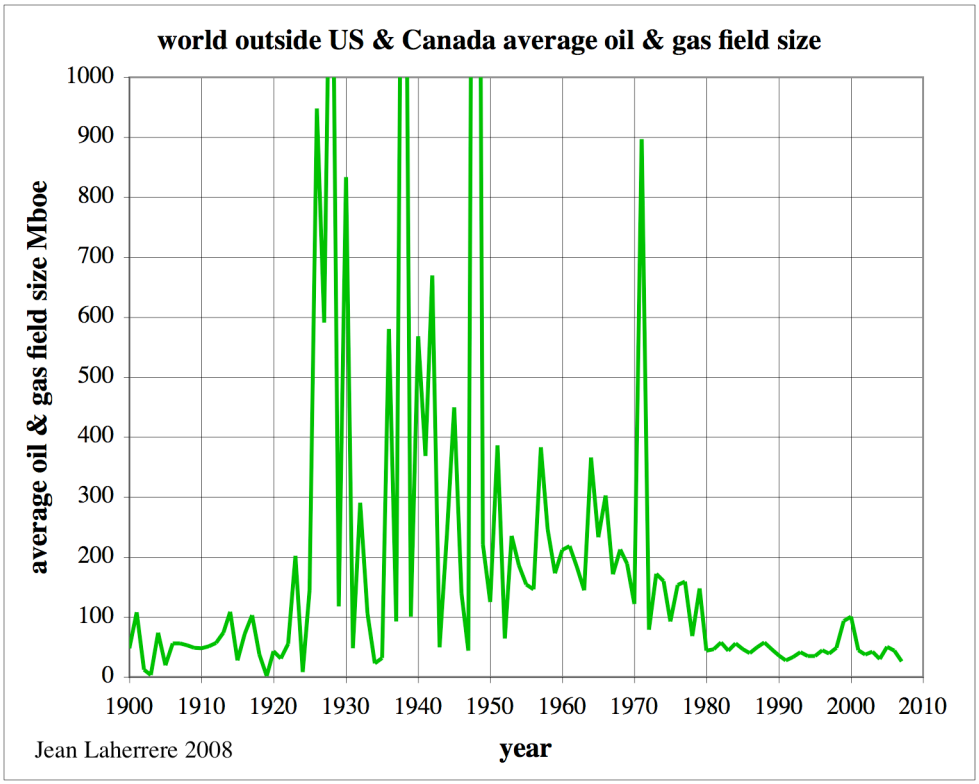

**-Synthesis**
**-World outside US & Canada**
The world outside US & Canada creaming curve is simpler and the success ratio is increasing



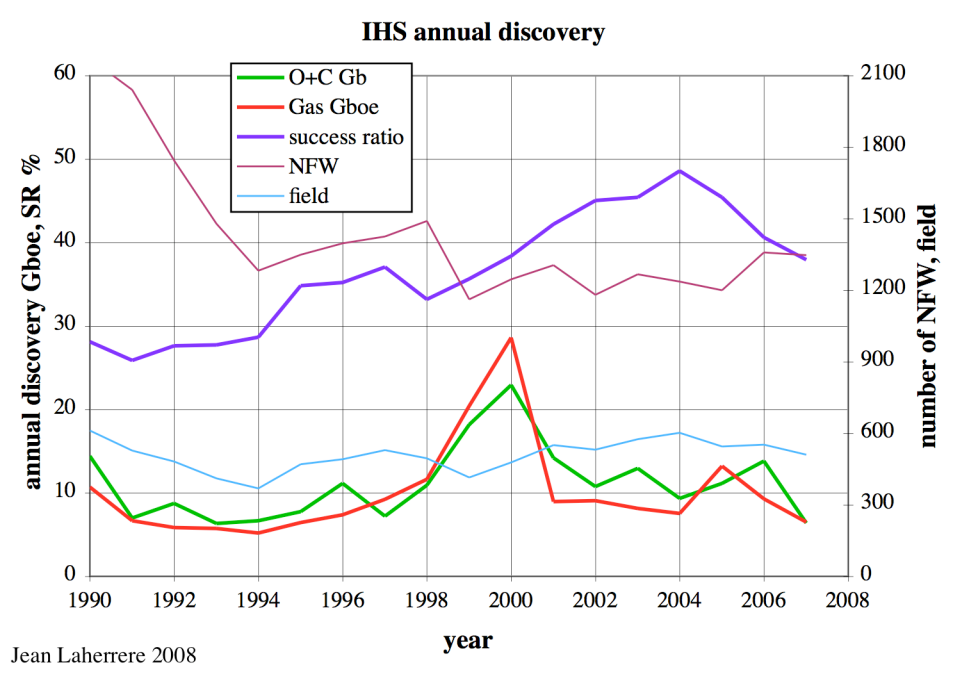

The oil success ratio was high around 1910 (drilling close to seeps) and was around 20% since 1930 to 1970. With better seismic and drilling in mature explored areas it reached 40 % in 2000, but failing lately



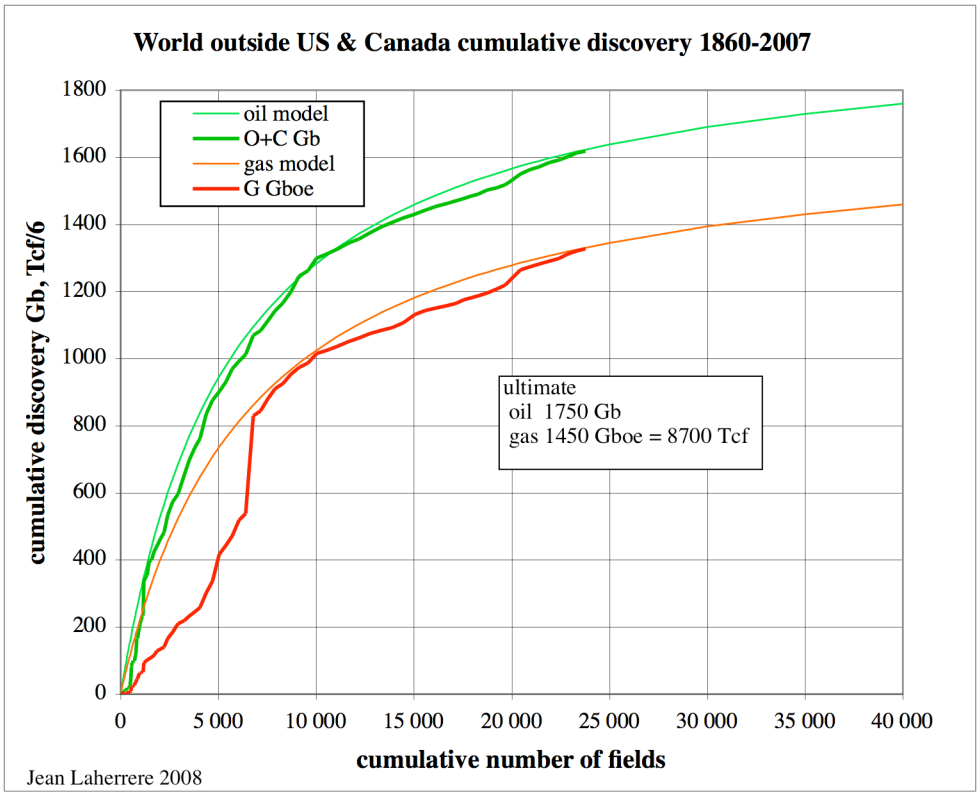

The oilfield average size is decreasing since 1950 (the spike of 1971 is North Dome in Qatar-Iran) from 200 Mb to 30 Mb



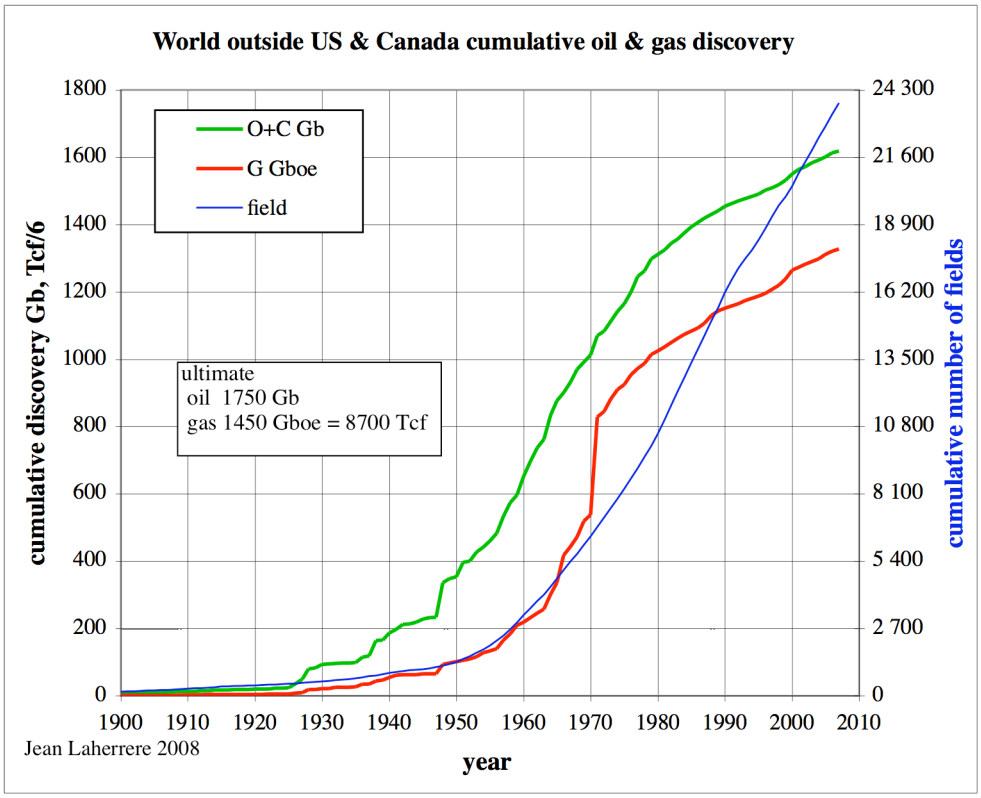

The values from IHS before corrections for ME and FSU for the period1990-2007 shows a decrease in NFW, but less in fields because the increase in the success ratio. The annual discovery is about 10 Gboe except for the year 2000, similar for oil and gas




The cumulative discovery versus the cumulative number of fields is easily modeled with on cycle leading to ultimates of 1750 Gb for oil and 8700 Tcf for gas (the sum of the different continents as above is 1773 Gb and 8950 Tcf)




The cumulative discovery versus time displays a S curve for oil but for gas North Dome spoils the curve because its huge size.

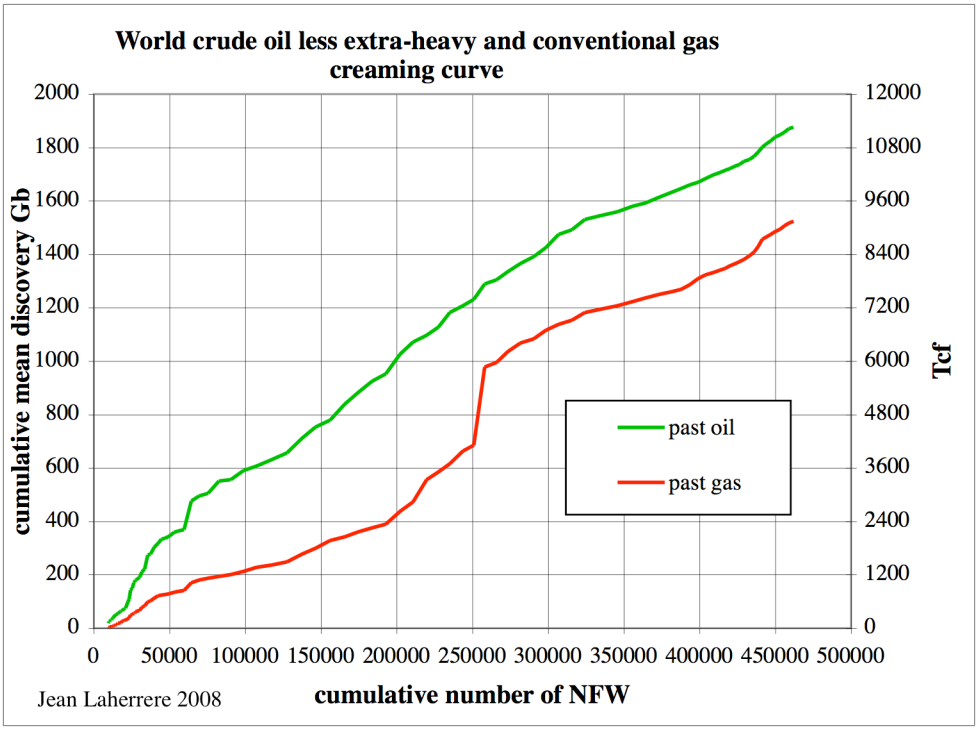



**-world**

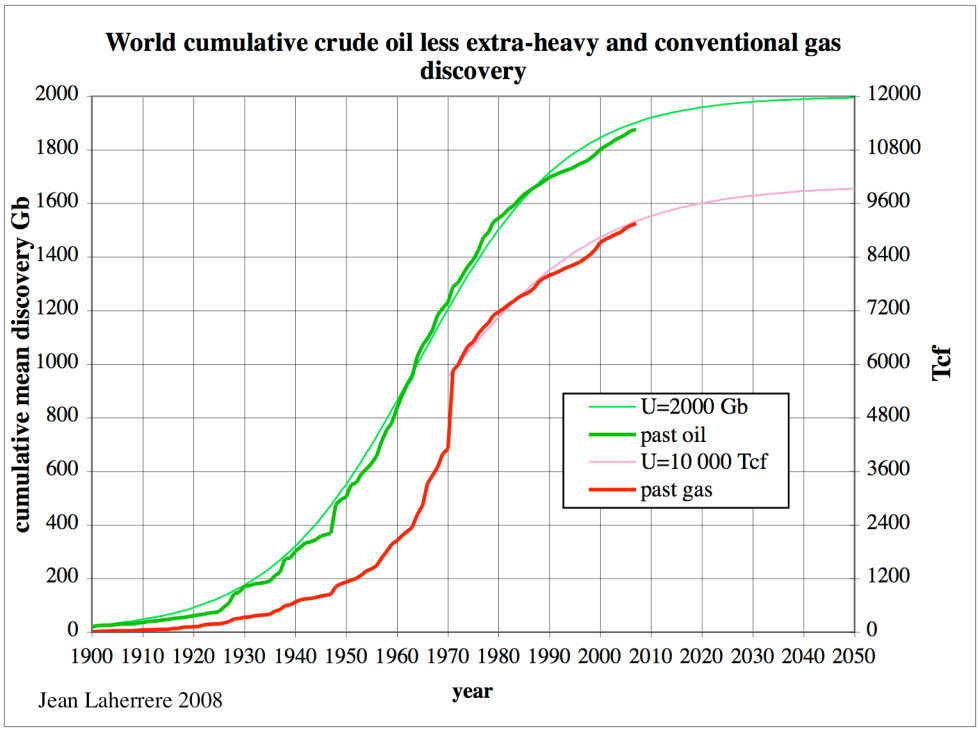
The aggregation of the above continents give a total of over 460 000 NFW for the world but 80% of NFWs are for US+Canada when the percentage of discovered is less than 14% for oil and 13% for gas: it is completely unbalanced and the sum should be erratic.

| cum end 2007 | conv oil Gb | conv gas Tcf | NFW | field | U oil Gb | U gas Tcf | YTF Gb | YTF Tcf |
|---|---|---|---|---|---|---|---|---|
| Africa | 205 | 647 | 10840 | 3150 | 250 | 800 | 45 | 153 |
| Australasia | 15 | 248 | 5378 | 1249 | 18 | 300 | 3 | 52 |
| Europe | 86 | 621 | 23317 | 4922 | 100 | 700 | 14 | 79 |
| Far East | 133 | 827 | 18809 | 4286 | 150 | 1000 | 17 | 173 |
| Latin America | 244 | 600 | 16222 | 4231 | 275 | 750 | 31 | 150 |
| Middle East | 690 | 3000 | 4323 | 1348 | 700 | 3200 | 10 | 200 |
| FSU | 245 | 2000 | 17257 | 4589 | 280 | 2200 | 35 | 200 |
| World – US+C | 1618 | 7943 | 96146 | 23775 | 1773 | 8950 | 155 | 1007 |
| US+Canada | 258 | 1180 | 365753 | ? | 290 | 1300 | 32 | 120 |
| world | 1876 | 9123 | 461899 | ? | 2063 | 10250 | 187 | 1127 |
| N. America frontier | 46 | 133 | 3250 | 551 | 65 | 180 | 19 | 47 |

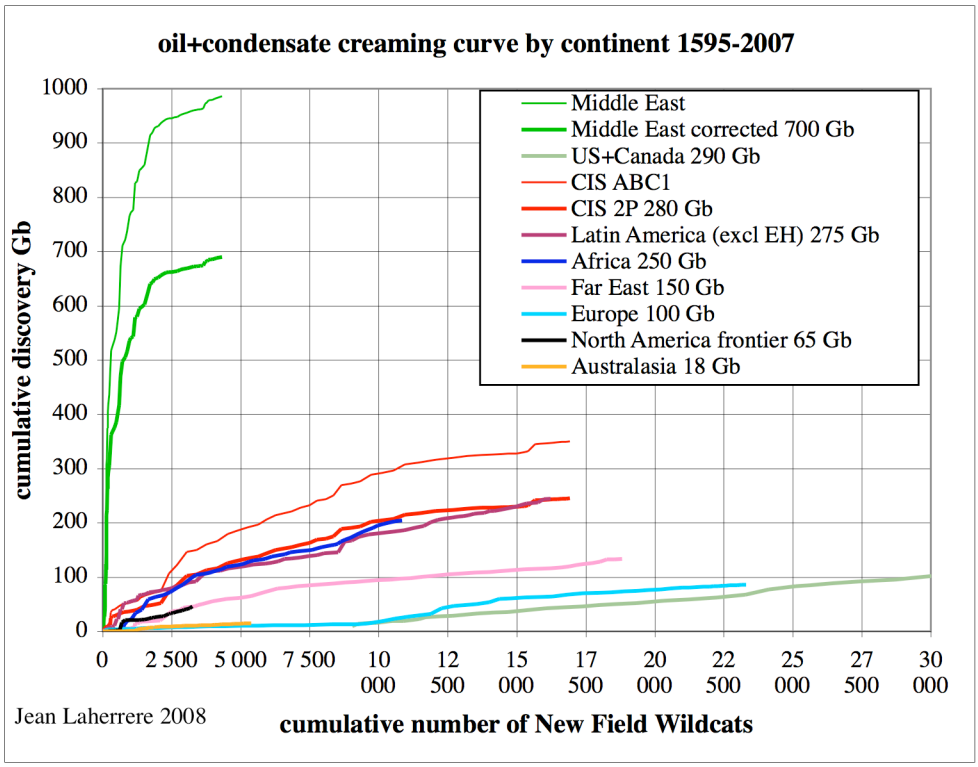
The world creaming curve does not look good because it is the addition of apples and oranges. The creaming curves for the US + Canada and the world outside US + Canada both display simple hyperbolas. But exploration in the US is different from the rest of world because in US oil and gas belongs to the owner of the soil. It is why there are over 20 000 producers in the US and the number of
130 producers in Canada to compare to one producer in Saudi Arabia.



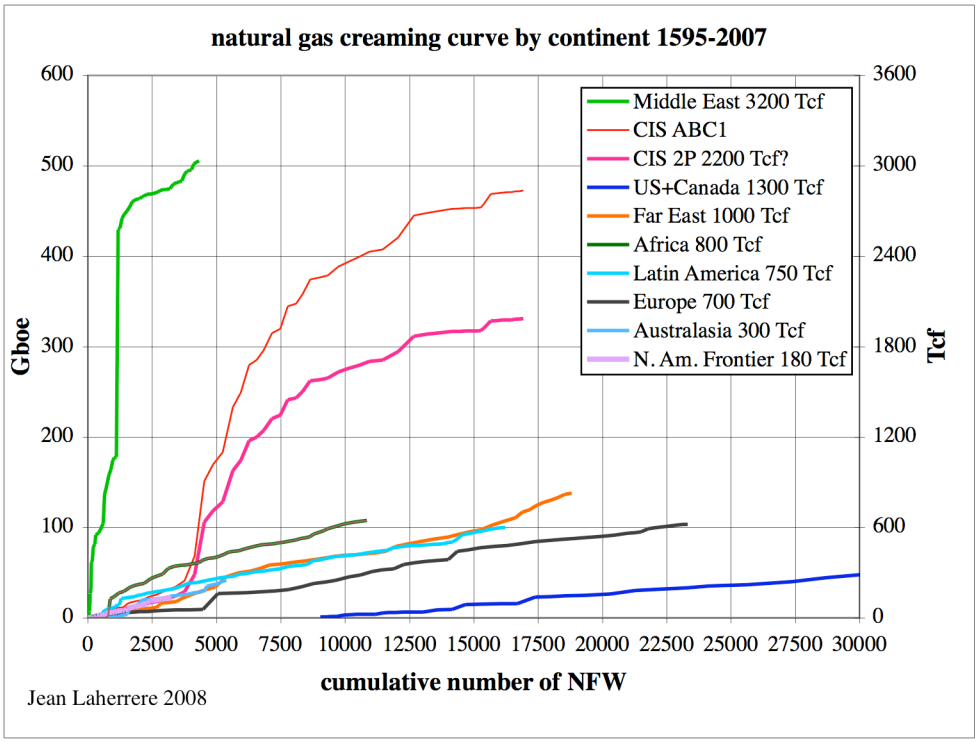

It is very unfortunate that it is nor possible to obtain the number of fields discovered in Canada to have the database complete for dealing with fields to extrapolate for world ultimates/
The only curve is the cumulative discovery versus time and aggregation leads to simpler curve. One single logistic curve is enough to check that our ultimates of 2000 Gb for crude less extra-heavy (conventional crude) and 10 000 Tcf for conventional gas look reasonable. Our rounding values show very well that the inaccuracy of such estimate is high, at least 10 %
I will not change my ultimate for oil if the data leads to an estimate of over 2200 Gb.



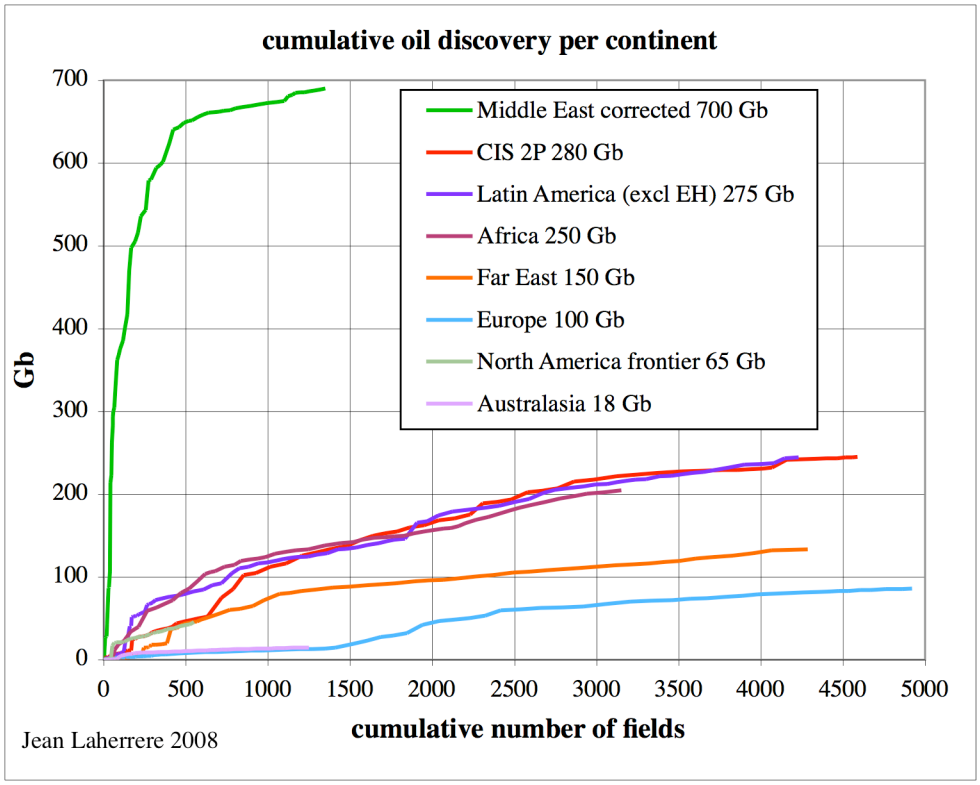

The synthesis of oil creaming curves per continent shows well that ME is quite gifted (because good source-rocks, good traps and excellent seals) , even after correction and that FSU after correction is identical with Latin America, Africa.
US+Canada with a higher ultimate needs over 10 times more drilling. Australasia has little oil.

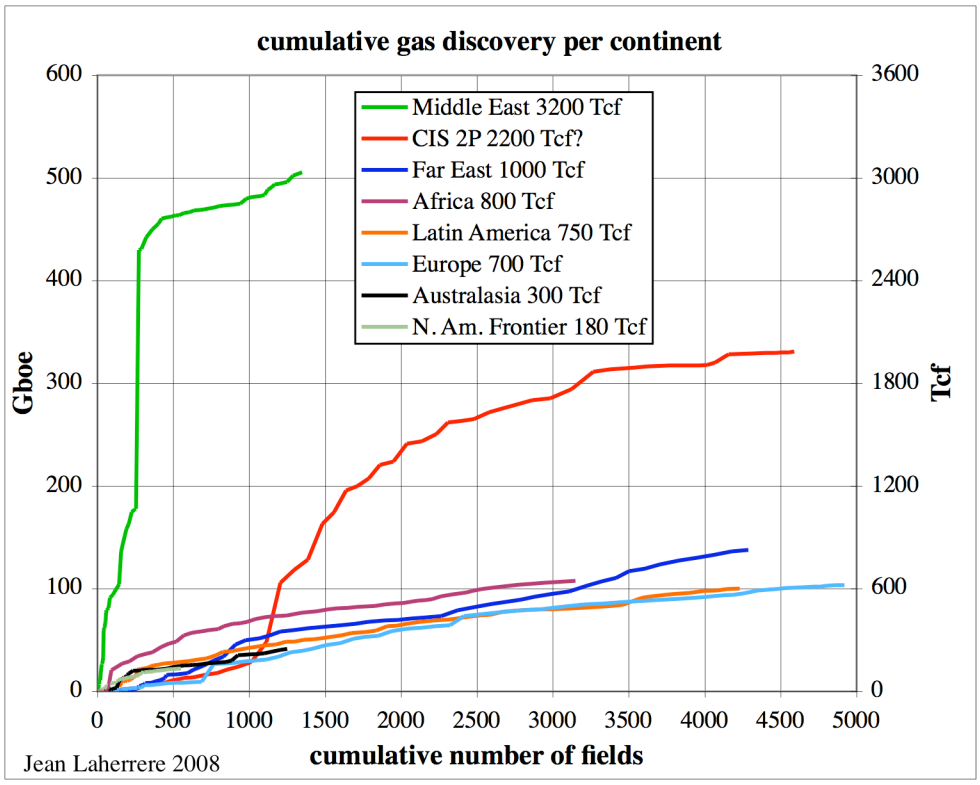



The gas creaming curve shows that again ME is gifted, much more than the FSU. Europe is Less behind and US+Canada needs as oil lot of drilling.

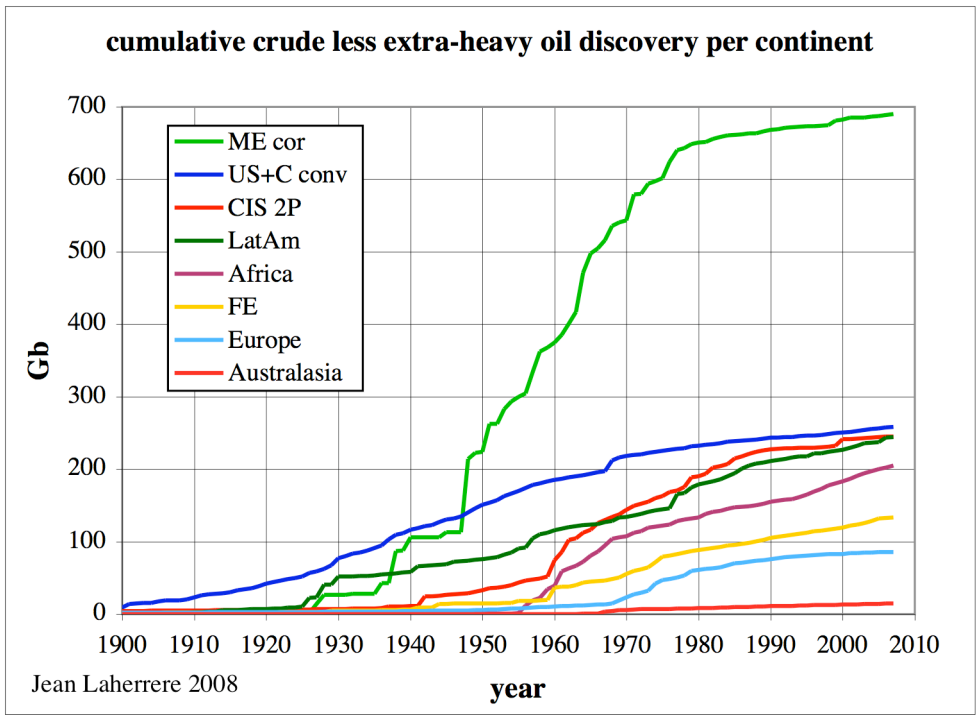


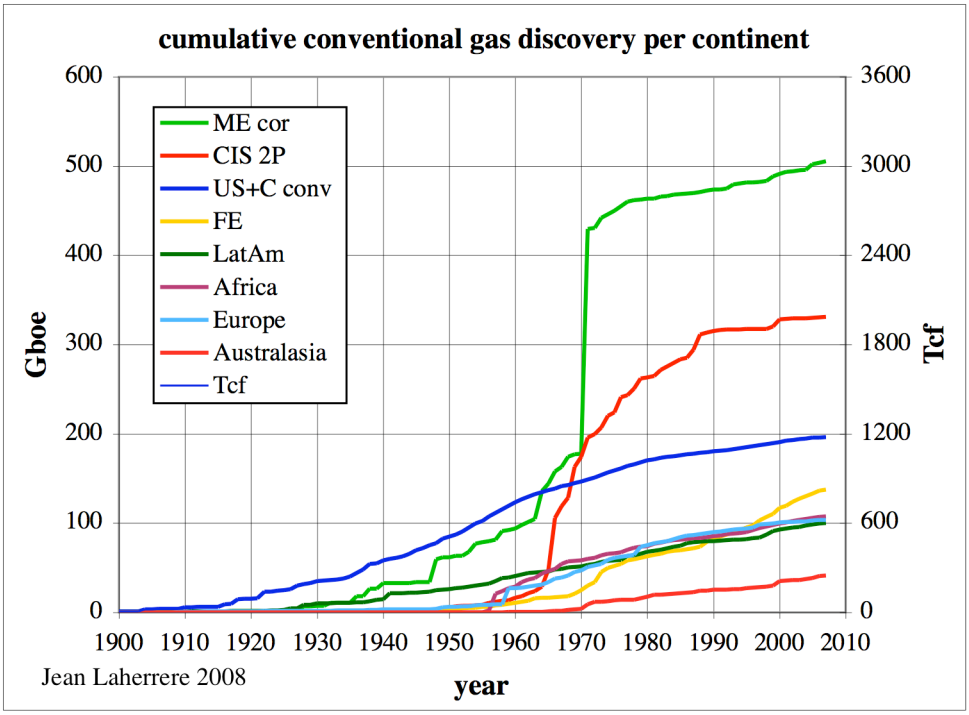

The cumulative discovery versus cumulative number of fields is interesting (data on NFW is not very reliable) but US+Canada cannot be plotted because the lack of field reporting in Canada (pool reporting).






The cumulative discovery versus time is a good comparison of what did happen at critical times like the oil shocks. FSU did find as much oil than US but in half the time.






A further paper will display the creaming curves and cumulative discoveries versus fields and time by country.