Distribution and evolution of "recovery factor"

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-1-**Definition**:

recovery factor (RF) = reserves divided by volume in place

-1-1-**Uncertainty**

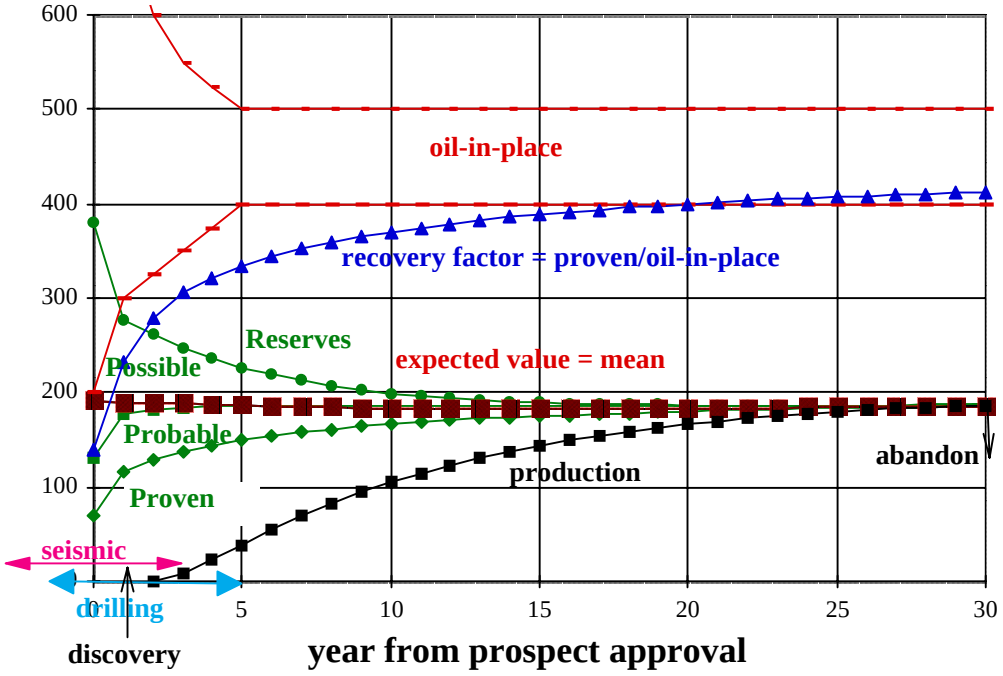
-large uncertainty on reserves:

which reserves?: proved = 90% or less?
proved & probable?
50% probability?
mean = expected value?
field growth ≈ probable

-uncertainty on reserves diminishes when production after decline sets in -larger uncertainty on volume in place estimated from seismic and wells, but knowledge does not improve from production data

-figure 1:

Evolution of uncertainty for reserves and recovery factor of a field



if production decline curves show upward reserve, it means:

EITHER (a) higher recovery factor OR (b) a larger oil-in-place**,**

It is normally attributed to (a) on assumed technologic progresses and not a more generous Nature (b).

-1-2-**Confidentiality**

Field reserves are confidential (US, France, ...) except in few countries where government requires data for development approval: UK, Norway

Oil -in-place are rarely given except for promotional reasons, also because it is not an input to modern simulation modeling. Reserves are computed straight from the model of the envisaged development. In IFP book "Basics of reservoir engineering" (Cossé 1993), there is only one page on recovery statistics, being a function of the type of reservoir.

-1-3-**Round number**

Usually recovery factor is taken as a round number or a fraction

At end of 1996, Norway (NDP) increased the Norvegian reserves by taking the recovery factor at 50% for oil and 75% for gas!

-1-4-**Politics**

Publishing "reserves" is a political act and depends of the image the writer wants to offer on the financial side . Publishing "recovery factor" is a promotional act on the technical side. Published values have to be treated with caution!

Russian classification on reserves was using the maximum theoritical recovery: Khalimov said in 1993 that these reserves are grossly exaggerated. Samotlor (largest Russian oilfield) recovery factor is taken at 51%, when now, with only 32% produced, the decline is at 15%/a with 92% watercut: 51% would not be reached! (Neftepromyslovoye)

-2-**Worldwide Data**:

-Published:

Roadifer 1987: reserves and oil-in-place for giants

Mac Gregor 1996: oil-in-place (mainly Roadifer) only

-Available files:

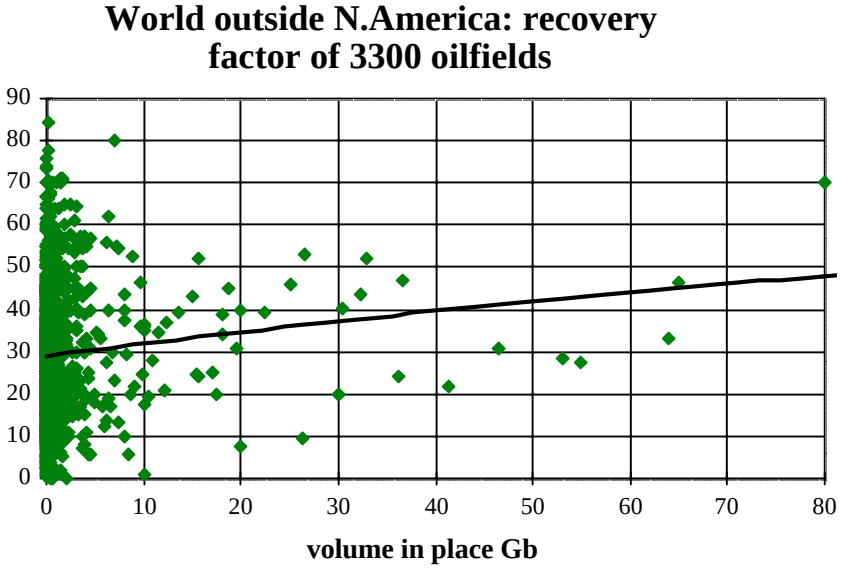
Petroconsultants for the World outside N.America (US+Canada)

-2-1-**Petroconsultants data**:

-2-1-1: **Oilfields**

-Versus the oil-in-place

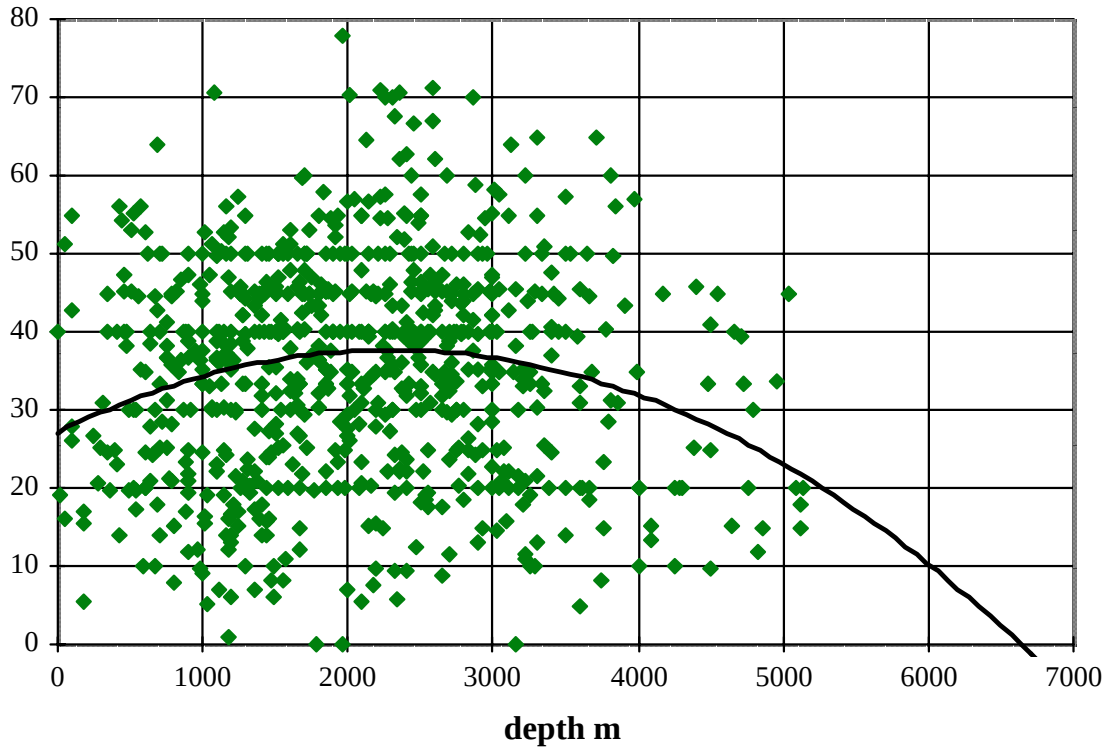
-**figure 2**: oil recovery factor versus depth for 3300 oilfields



Recovery factor increases with oil-in-place: an average of 30% for the small fields (with a huge range from 0% to more than 80%) and of 50% for the largest fields (range from 30% to 70%).

-Versus depth of the reservoir for 800 major oilfields
-figure 3:

World outside N.America: recovery factor of 800 oilfields versus depth

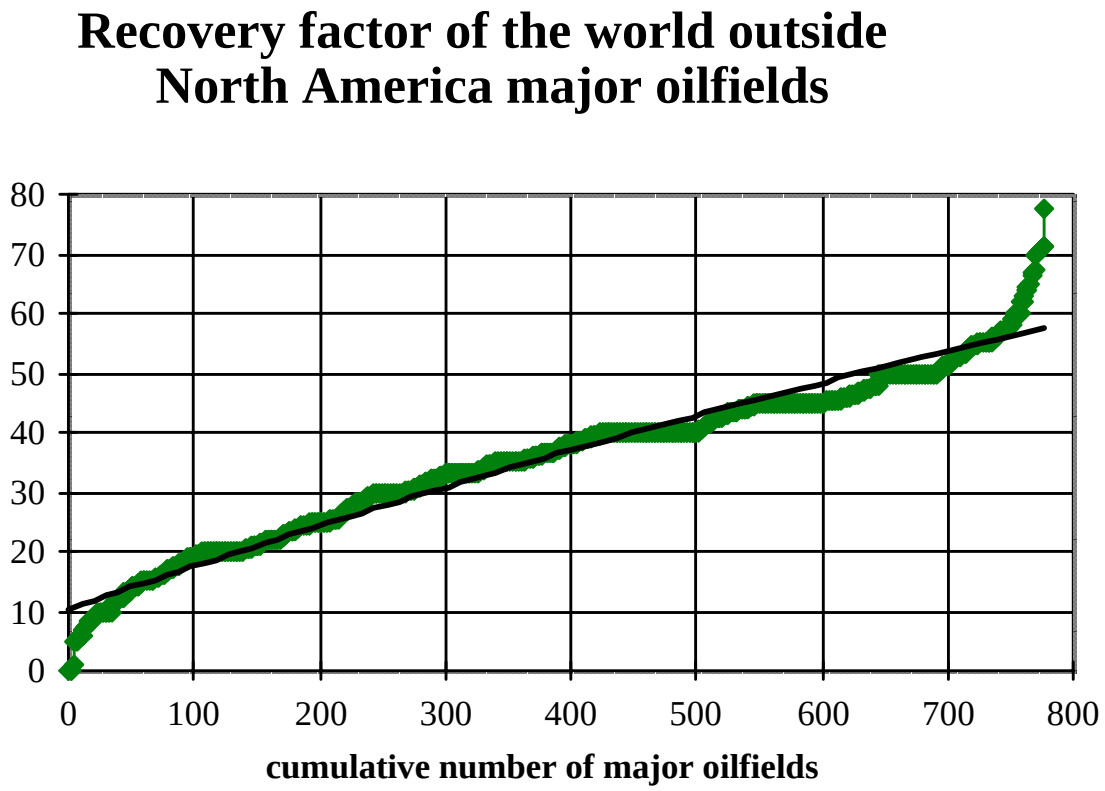


The parabolic trendline peaks at 40% for a reservoir depth of 2000 m and it is fascinating to find that the recovery factor trendline is nil for reservoirs deeper than 7000 m, which is the reality. The range is very large, but shortens for reservoirs deeper than 4000 m.

-Distribution of oil recovery factor:

The plot of the cumulative number by increasing recovery factor on figure 4 displays a almost linear trend from 15% to 55%, but with steps for most of round numbers as 20%, 25%, 30%; 33%; 35%, 40%; 45%, 50%.

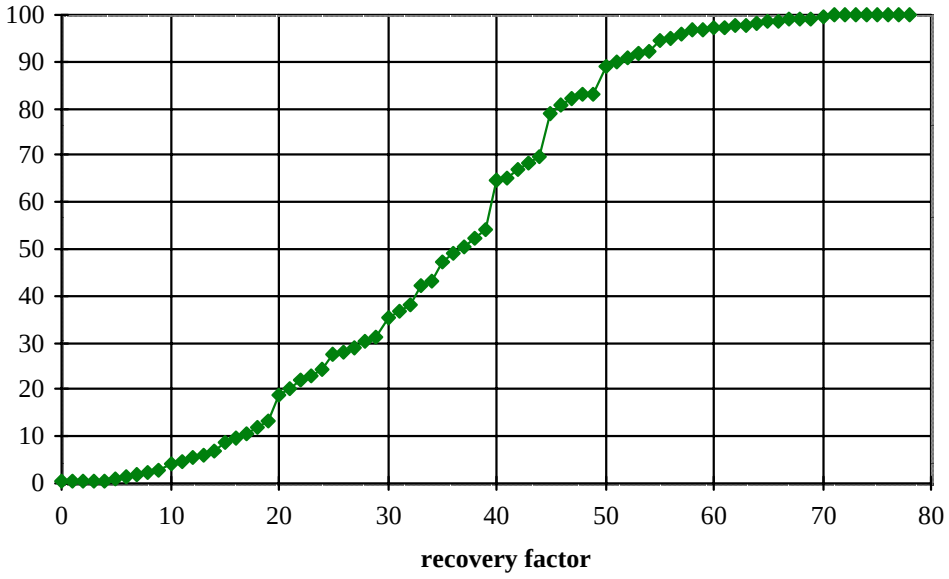
-figure 4:



The graph on figure 5 of the same major oilfields given as a percentage of the total fields displays the same steps and indicates that 10% of the fields have a RF of less than 10%, 50% a RF of less than 35% and 90% a RF less than 50%.

-figure 5:

World outside N.America: percentage of major oilfields with a recovery factor less than

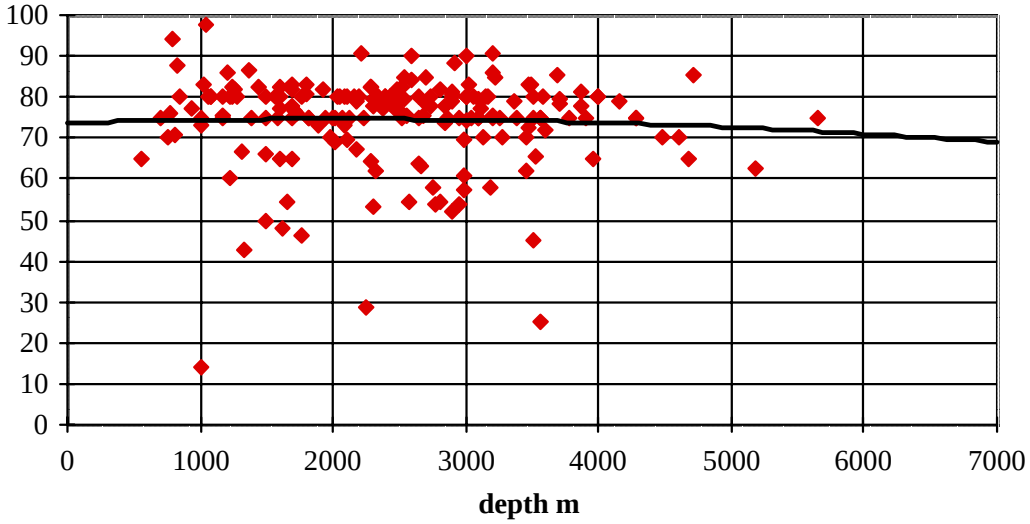


-2-1-2: **Gasfields**:

The recovery factors of the non-associated gasfields with reserves over 1 Tcf are plotted versus the depth of the reservoirs on figure 6. The trendline shows that depth has no effect on recovery factor, in contrast to oil, with no limit at greater depths. The average RF is around 75%, but with a range from 30% to almost 100%.

-figure 6:

World outside N.America: recovery factor of non-associated gasfields (>1Tcf) versus depth



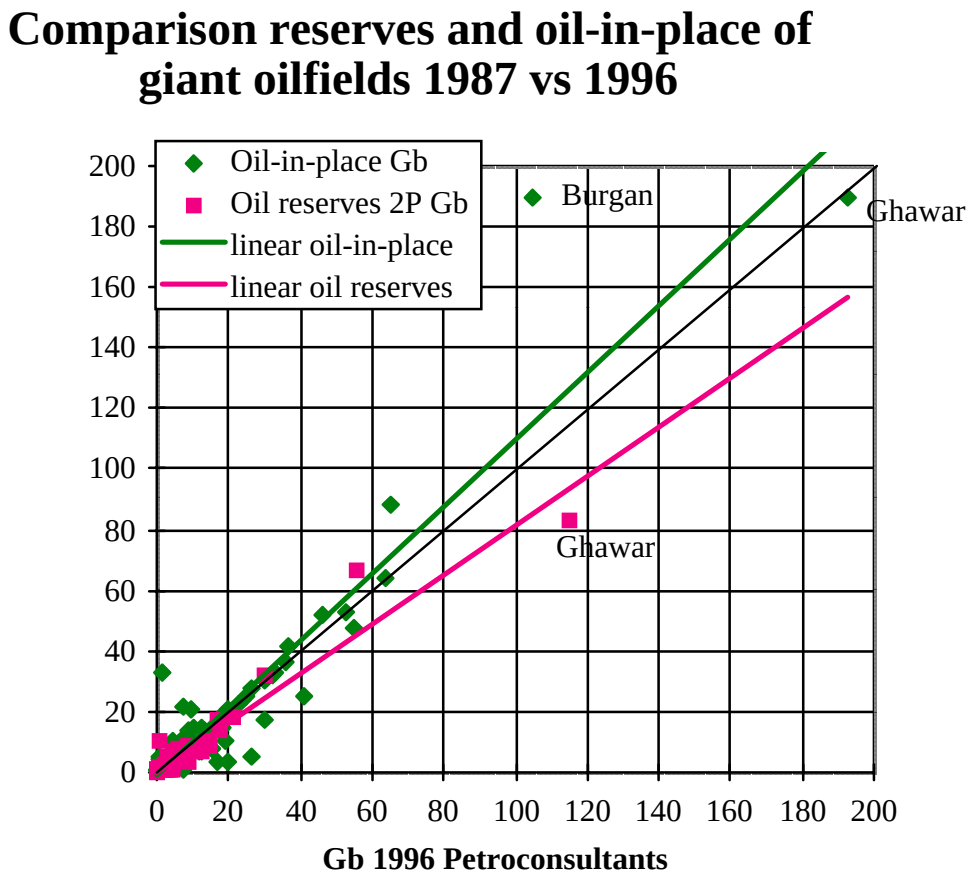
-2-2: **Comparison with Roadifer 1987**

-Reserves and oil-in-place

Figure 7a displays the values of Roadifer 1987 giant oilfields compared to the values for the same fields by Petroconsultants 1996.The trendline for oil reserves is below 45°. It means that Petroconsultants 1996 reserves values are on average a little higher than the 1987 Roadifer values, when the trendline for oil-in-place above 45°, meaning that 1996 oil-in-place values are a little lower than the 1987 values. But the difference is small, especially for the fields smaller than 20 Gb. The larger fields, in particular Ghawar, greatly influence this trendline, but Ghawar reserves are questionable, Petroconsultants reports 115 Gb when the discoverer Chevron reports on the web only 60 Gb, the difference is equivalent to the reserves of the North Sea!

But the same data on a log-log display diminishes the influence of the larger fields. On figure 7b, the plots of both oil-in-place and reserves appear to be centered on the 45° line, meaning on average that the values have not changed from 1986 to 1996.

-figure 7a



-**figure 7b** on a log-log format

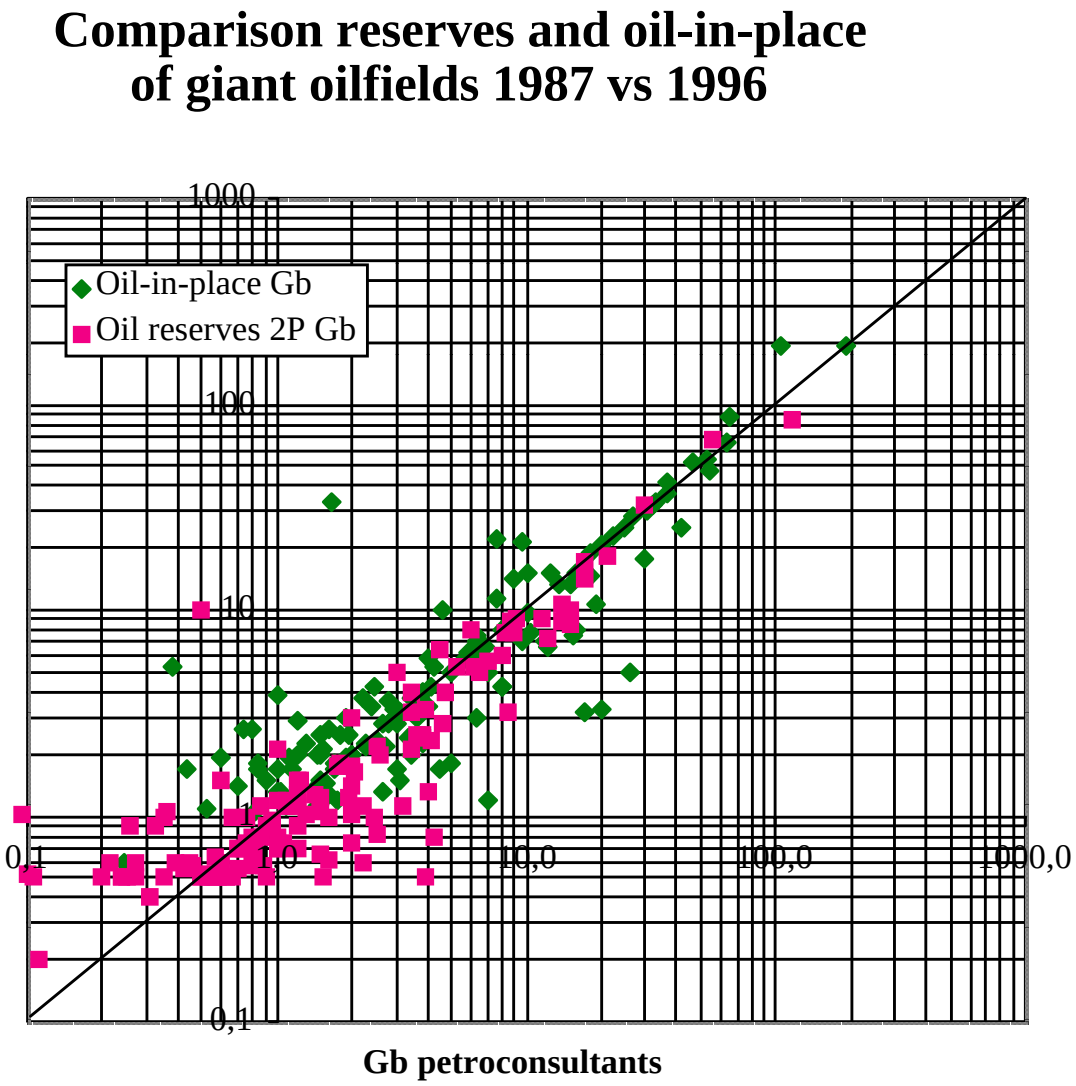
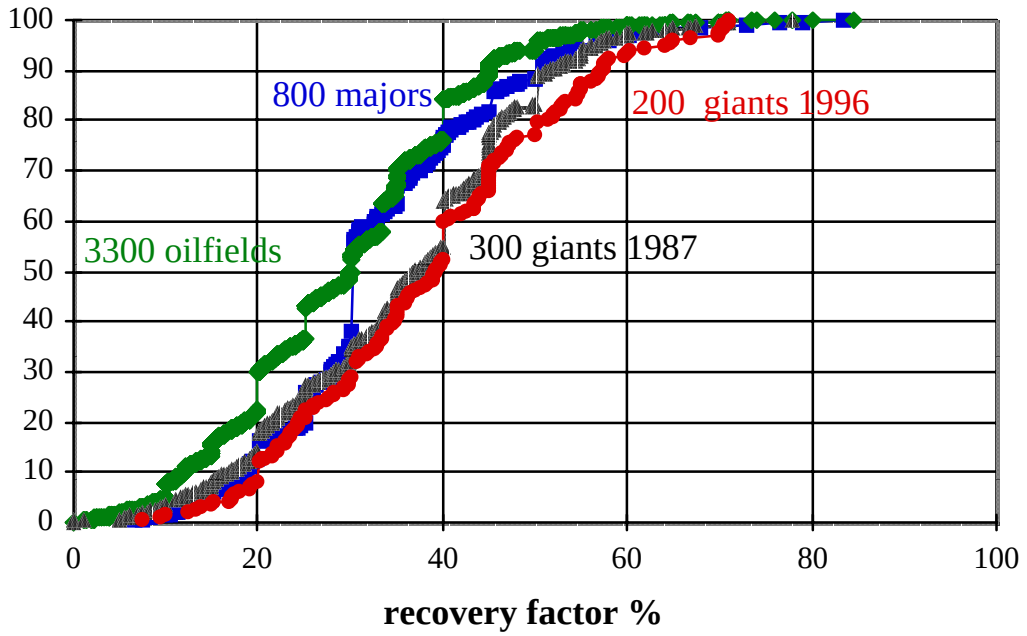


Figure 8 displays the distribution of recovery factor (as figure 5) with the breakdown for 1996 of the 200 giant and 800 major oilfields and the comparison with the 300 giants 1987. It is interesting to notice that for the giant oilfields, the distribution is identical betwween 1987 and 1996 for the poor reservoir fields (RF<40%), but the values of RF for good fields (RF>50%) have increased from 1986 to 1996. For the 1996 major fields, the poor ones (RF<30%) and the good ones (RF>50%) are close to the giant distribution, when in the middle they are close to the average fields.

-figure 8:

World outside N.America:distribution of oil recovery factor and comparison 1996-1987

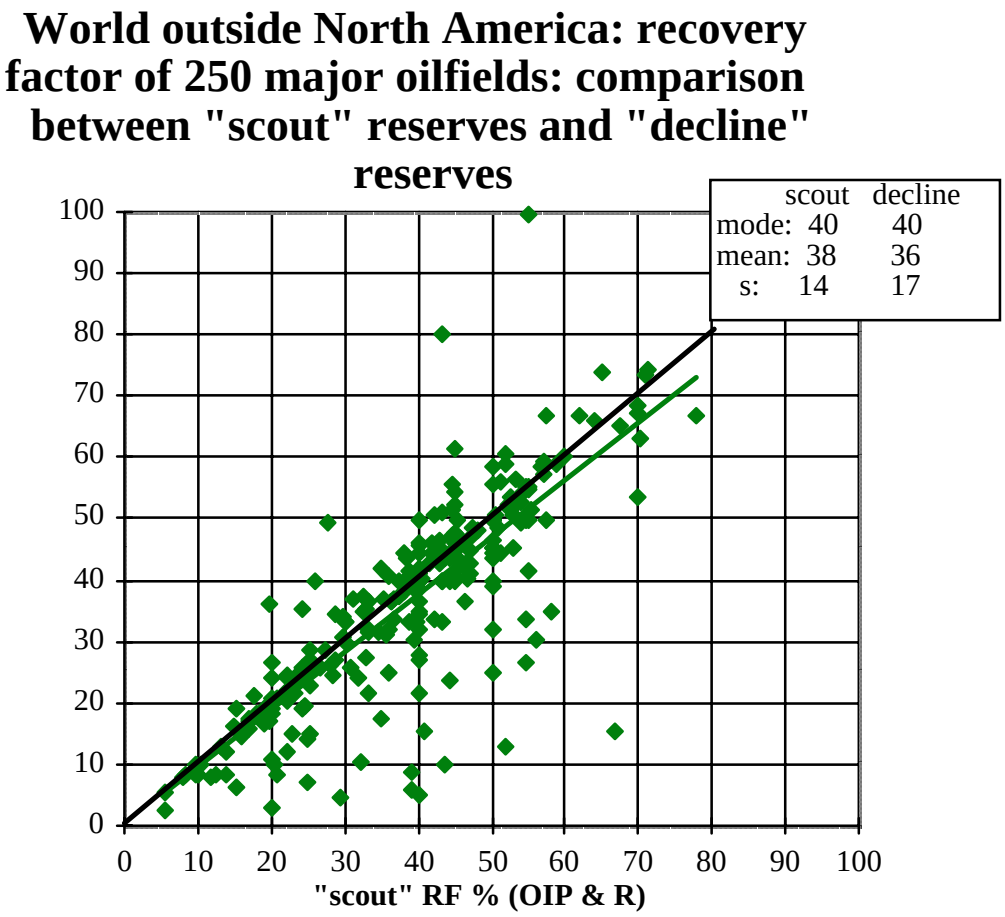


-2-3-**Comparison with reserves estimates from production decline**

From the Petroconsultants annual production data of every major fields of the world outside N.America, we have estimated the reserves of more than 500 oilfields and found that the (ultimate) reserve estimates from "production decline" are 16% lower than the reserve estimates reported by Petroconsultants (from scouting) and 42% lower for "remaining reserves" (ultimate reserves minus cumulative production).

Figure 9 displays the RF computed from the "decline" estimates versus the "scout" values, assuming that the "scout" oil-in-place number is correct. The plot is widely spread axed on the 45° line, with a trendline slightly below. The two distributions of values have a similar mode (RF=40%), but a different mean, 36% for the decline values and 38% for the scout values. The standard deviation is larger for the decline values (17 against 14), as the oil-in-place is not homogenous.

-figure 9:



-3-**Influence of technology and investment on recovery factor**

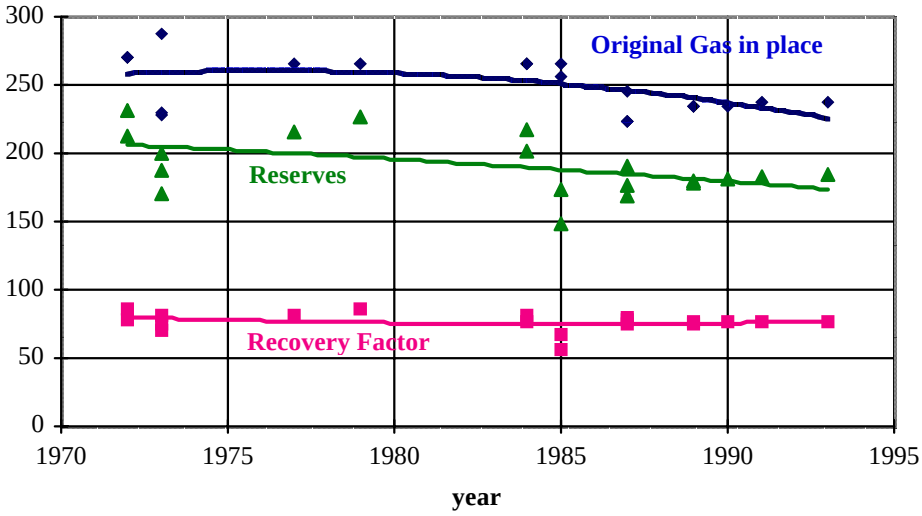
Estimates of recovery factor varies largely within the operator's organisation, the partners and in published reports. Reservoir engineers start with a low value in order to not be contradicted by Nature. In North Sea, water flooding was estimated to leave in good reservoirs as much as 30% residual oil behind, but Nature was generous and in fact swept all oil out of reservoir, recovery factor increases, not because of better technology but because of initial pessimistic estimates.

Frigg field is now depleted and good technical articles (Torheim 1996) give reliable informations on reserves, gas-in-place and recovery factor during the development and production of the field, seismic and one well took place near the end of production as discrepancy arose between the model and facts. Figure 10 shows that the decrease in gas reserves follows the decrease in gas-in-place, the recovery factor remaining about the same around 78%, but varying from 56% to 86%.

A study by a Statoil team of the evolution of the North Sea reserves (Hermanrud et al 1996) found that there are as many negatives revisions as positive revisions.

-**figure 10**:

Frigg: evolution of OGIP, RF and reserves with time and works

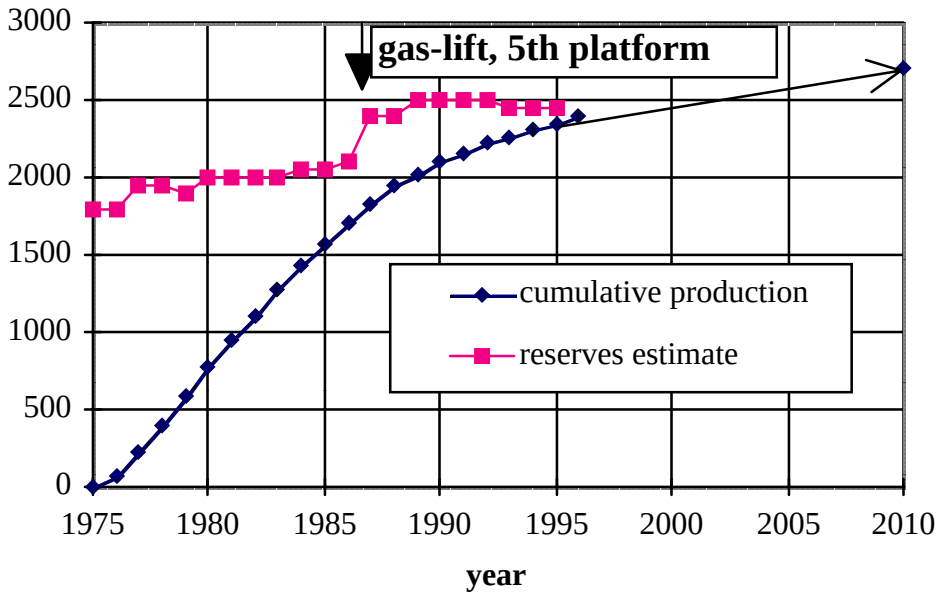


Investment and technology is said to iimprove recovery factor and great hopes are put in such increase. A geochemist, Cl.Allégre (now minister for Education), wrote in 1996 that, with 3D, it is possible to hope to recover 80% to 90% of the oil!! In fact, most of the time, investment and new development increases production, but not ultimate reserves.

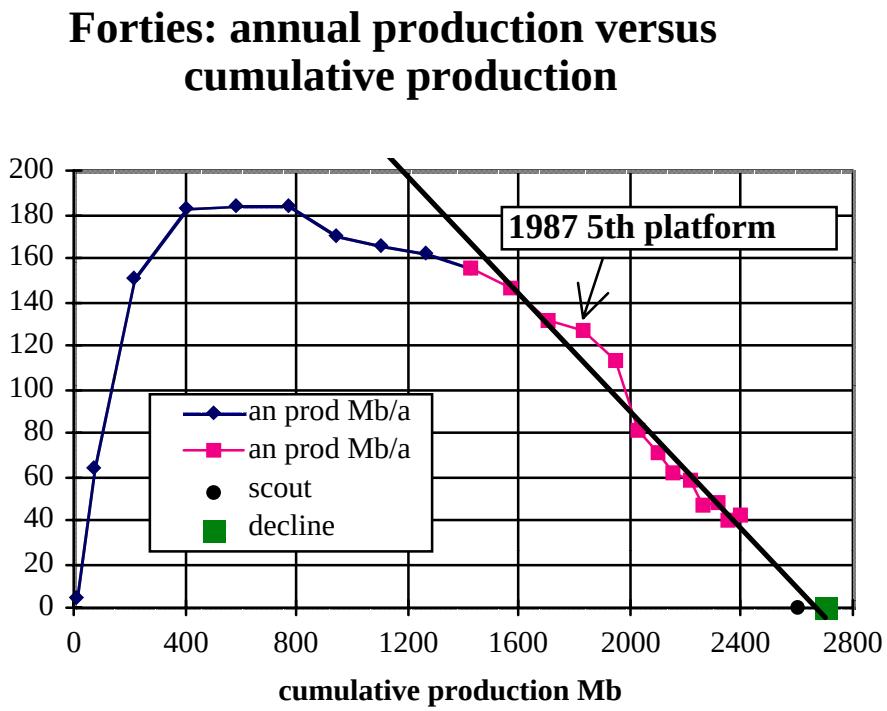
Forties field is a good example. Figure 11a displays the published reserves and cumulative production versus time. In 1986, ultime estimate around 2000 Mb was so close to cumulative production that it was obviously too low. In 1987 because of new investment and new development in a fifth platform with gaslift, estimate was increased to 2500 Mb and this value in 1995
is still too low. Figure 10b with annual production versus cumulative production shows that the ultimate is around 2800 Mb and could have been correctly estimated in 1986. The 1987 investment has increased annual production in 1987 and 1988, but the ultimate stays constant.

-figure 11a:

Forties: cumulative production and reserve estimates versus time



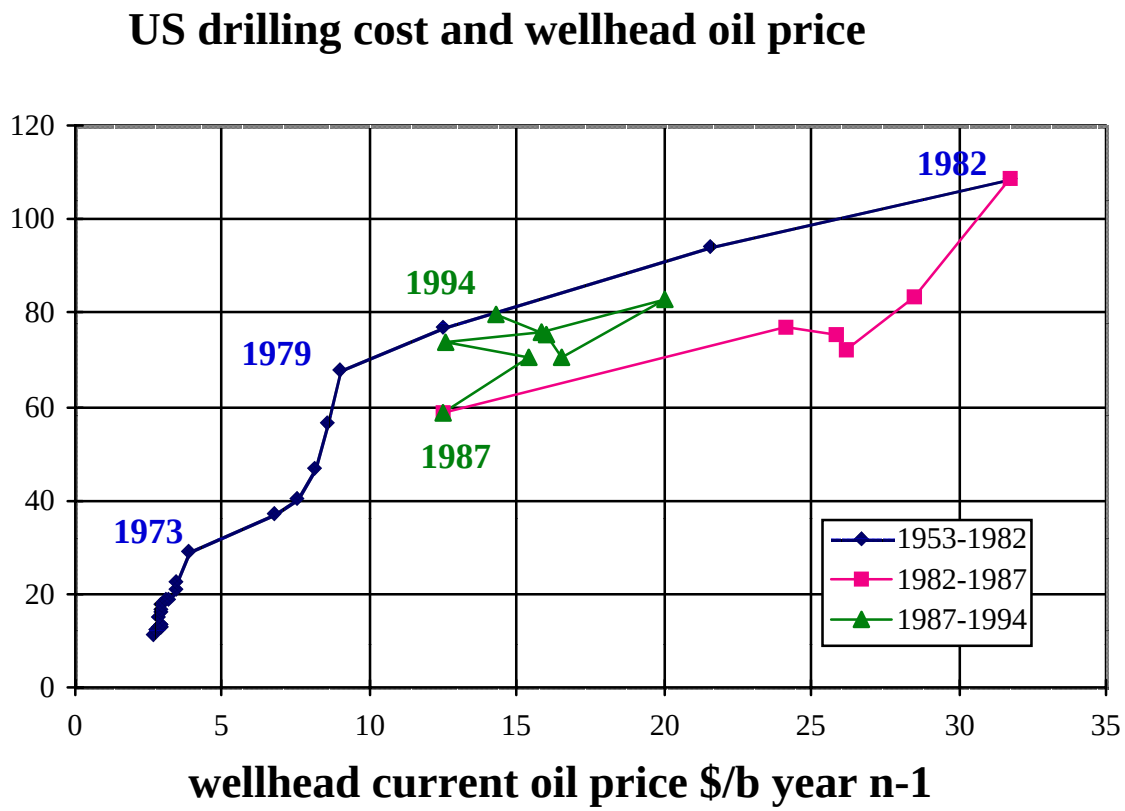
-figure 11b:


Forties: annual production versus cumulative production
200
180
160
140
120
100
80
60
40
20
0
0
400
800
1200
1600
2000
2400
2800
1987 5th platform
an prod Mb/a
an prod Mb/a
scout
decline
cumulative production Mb

-Influence of costs on recovery factor:

North Sea costs have diminished from the crazy years of the first half of the 80s to 1996 because of the learning curve (decrease in drilling time) and of the decrease in dayrate. This decrease was extrapolated by some who said that with such lower costs, any marginal field could be developed and recovery will increase. To avoid the learning curve influence, we have plotted, from API data book, the US average drilling cost versus wellhead price (delayed by one year) and found a very good correlation between cost and oil price, without any influence from technology.

-figure 12:



-Conclusions

Recovery factor is an uncertain parameter (usually taken as a rounded value) and usually ignored by reservoir engineers in their new technology of modeling production.

The recovery factor is meaningless as long as there is no consensus on reserve definition. The last SPE/WPC (WPC Oct 1997) definition is a poor compromise and likely will not be followed.

Recovery factor computed with proved reserves (neglecting probable reserves) should be considered a political parameter. Only recovery factor using expected (mean) values should be considered.

As volume-in-place is estimated mainly from seismic and wells data, its estimate stays uncertain when reserve estimates improves with production decline.

Recovery factor increases most of the time because of poor estimate at the beginning. When using proper reserve estimates, recovery factor does not change too much with time.

Recovery improvment due to new technology, as enhanced oil recovery, is already completely integrated in the present reserves estimate (Ghawar recovery factor is taken as 65%).

Recovery factor depends mainly on the reservoirs characteristics and the drive mechanism. Oil recovery factor varies from almost 0% to 80%. Thinking that its average of 35% could be raised to the value of good reservoirs is as much wishfull thinking as a parent wanting their child to look like Marilyn Monroe or Paul Newman and has a brain like Einstein or Shakespeare. Geological conditions (as genes) cannot been changed.

-**Acknowlegdments**:
Petroconsultants is thanked for allowing use of their database for plotting all these graphs.

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