Iraq's Oil Reserves Revisited & Implications
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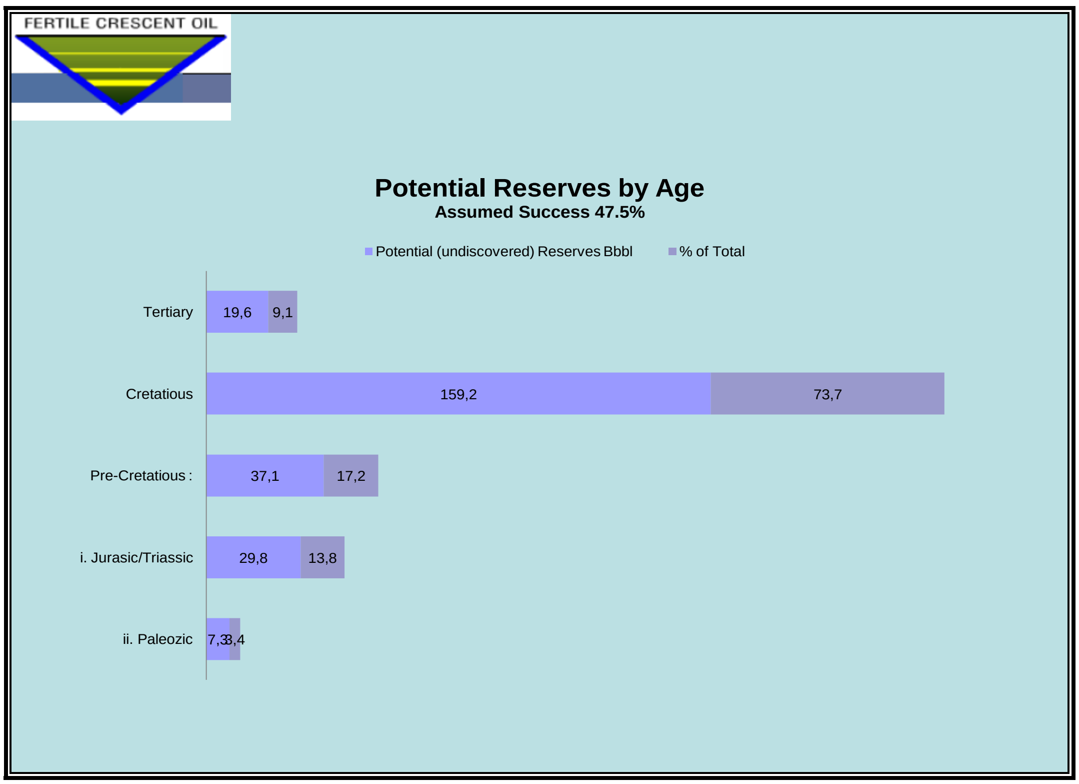

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1.0 Geological and Tectonic background

The Middle East region of hydrocarbon riches falls between the Arabian Shield on the one side and the Zagros mountains on the other.

The stratigraphy of the region is simplified by the fact that clearly recognisable rock units can be followed for long distances without unduly abrupt changes in facies.

The majority of the oil reservoirs in the Middle East (ME) range in geological age from the Tertiary Oligo-Miocene period to the Middle Jurassic period. Within some countries, hydrocarbons have been found in reservoir rocks of widely different ages. Thus, in Iraq, oil reservoir formations range from the Oligo-Miocene period to the Triassic. Iraq could be considered as a wide NW-SE oriented trough, the centre of which contains the youngest strata with a sedimentary cover having a thickness in the range of 5-13 kilometer.

1.1 Tectonic Framework

Iraq occupies the north-eastern corner of the Arabian Plate and over 95% of its territory lies within the Arabian Shelf units, whereas the rest, a narrow strip along the Iraqi-Iranian border, represents the Zagros Suture unit which separates the Arabian and Eurasian Plates.

Looking at the tectonic framework of Iraq, virtually all of Iraq is part of the Arabian sedimentary basin extending from the Arabian-Nubian platform in the west and the Alpine folded geosynclinals units of the foredeep in the east. This vast sedimentary basin dates from pre-Cambrian.

Iraq is made up of two main divisions of *Stable and Unstable Shelves* of about equal areas. The Stable Shelf occupies the West and SW parts of Iraq and the Unstable Shelf in the East, North and NE parts of the country. Each is divided into a number of tectonic zones and some of these are divisible into sub-zones. Iraq is additionally dissected by a number of major NE-SW trending transverse faults, which cut across both Stable and Unstable Shelves and carry a strike-slip component of movement as well as a vertical component.

There are various structural plays which can be divided according to their prospects, geological age and tectonic setting to coincide with the tectonic framework:

- **The Stable Shelf**

The Stable Shelf roughly coincides with the Western and Southern Desert geographic divisions of Iraq. It is tectonically divided into a western Rutba-Jezira Zone and an eastern Salman Zone separated by the N-S trending Salman-Sharaf Divide where the basement is at its shallowest (about 5-6 km below sea level).

Through gravity modeling and magnetic, seismic (though very limited) and supplementary oil and water well data (with only few exploration well), the Stable Shelf is shown to possess thick sedimentary successions on either side of the Salman-Sharaf Divide. The successions principally consist of Paleozoic sediments.

- **The Unstable Shelf**

It is divided into two main zones. The NW-SE trending Mesopotamian Zone extends across the alluvial plains of the Euphrates-Tigris valleys continuing from the Salman Zone to the Iranian border and wedging out in the NW in an apex. The second main zone is the Folded Belt which is subdivided into a Foothills Zone, a High Folded Zone and an imbricated Zone, extending over the foothills and ranges of Zagros and Taurus Mountains.

1.2 The Hydrocarbon Prospect

The hydrocarbon prospects of Iraq or the ME are specifically addressed by their petroleum systems, geological ages of the reservoirs housing the accumulations, and sedimentological history from early Paleozoic to the Miocene.

For oil occurrence there are conditions which need to be met. They are:

P&A. Conditions for Oil Occurrence

➢ **Source Rock (the kitchen)**
➢ **Reservoir Rock (a porous and permeable reservoir and impermeable seal)**
➢ **Trap (a structural dome like housing)**
➢ **Timing**

The focus is, in particular, on *the presence and maturation of the source rock levels charging the reservoir rock* of *the structural anomalies (Traps*) available *to trap and preserve them under suitable seals.*

The hydrocarbon prospects of Iraq, however, have been enriched by the presence of numerous *plays* of identified petroleum systems, geological ages of the reservoirs housing the oil accumulations and the sedimentology history which extends from early Paleozoic to the Miocene providing the right conditions for the occurrence of oil.

The various tectonic zones in Iraq are dominated by one or more petroleum systems. Generally, the *stable shelf* is dominated by the *older system* whereas the *unstable shelf* is dominated by the *younger ones*. The presence and maturation of the source rock, the *'kitchen'*, charges these reservoirs, from within or a far, of the structural anomalies (or the like) available *to trap* and *preserve the hydrocarbon under suitable seals.*

Our Petrolog & Associates (P&A) in-house study of 1997 included, among others, hydrocarbon prospectivity shown by typical *lithology columns* for each tectonic zone. They help to show at a glance the main source level charging the targets and help to find the formation that would seal the accumulation being explored for. In addition, other productive or potentially productive objectives in the tectonic zones are identified.

2.0 Exploration Drilling

As shown above, Iraq is almost entirely underlain by Silurian and/or Jurassic and Cretaceous rich formations of sufficiently mature source rocks. Apart from the Cretaceous, the others prospects have only sparingly been touched by the drill. The drilled density has been as low as *one exploratory well per 2,900 sq km*.

Thus far 113 *structures* (counting both domes of Rumaila as one structure) have been explored, out of which 79 were successful (from 1903-1992), *giving a success rate of 7 structures out of 10.*

The exploration drilling intensity increased from about 1.5 wells per year (88 wells in 59 years (1903 to 1962) during the concession era, to nearly three wells per year (67 wells in 23 years, from 1969 to 1992). The overall success has been *3+ out of 4* wells; on a cumulative basis: 120 successful exploration wells out of a total of 155, inclusive of delineation and deep test wells.

The percentage of *successful exploration wells* in the country started at 50% and maintained a higher level at *77%* by the time the Akkas well was drilled in 1992.

155 wells were drilled to investigate 113 structures (excluding Ur and Um Qasr for lack of reliable information), i.e. a rate of 3 wells per 4 structures which is a very low rate of exploration wells (including delineation and deep tests) per structure.

Such low exploration well intensity per structure (though often structures are over 10 kilometres in length) suggests the requirement for further evaluation of the past dry or marginal fields.

What is rather unique is the fact that even during the initial phase of exploration from 1905 to 1939 the percentage of successful structures remained above 50%, increased to 70% by 1956, dropped to above 60% in 1960 and then started to build-up gradually to its present level of 70%. And, recent exploration in the north east of the country, carried out by the independent oil companies has demonstrated the same level of success.

3.0 Development of Reserves

The build-up of reserves has been impressive. Some *125.4 B bbl* (in accordance with per field estimate of our P&A study of 1997) of crude oil reserves have been discovered in 79 fields from 1903 to 1992, *giving rise to 1.59 B bbl per field, 0.9 B bbl per explored structure and 0.81 B bbl per exploration well.*

It is important to note that the total reserve of 125.4 B bbl includes 37 discovered but not developed structure whose reserves are not assessed. However, each has been assigned a conservative reserve figure of 0.1 B bbl.

No doubt when these fields are developed their true and realistic reserves will be revealed.

The official proven reserve figure stood at 100 B bbl in 1989, was changed to 112B bbl the following year and was kept at this level until 2001 when it was changed to *115 B* bbl, giving original reserves of about 138 B bbl, compared with our estimate of 125 B bbl then.

The reserve build-up from 1903 to 1992 was characterised by sudden large increases due to the huge reserves of the giant and super giant oil fields, Kirkuk in 1927 (22.4 B bbl), Zubair in 1949 (4.75 B bbl), Rumaila in 1953 (27.25 B bbl), West Qurna in 1973 (8.0 B bbl), East Baghdad in 1976 (11.0 B bbl) and Majnoon in 1977 (11.0 B bbl). They were taken as the most likely from among the very many figures given by government and oil industry sources.

Clearly, Iraq reserves build-up has resulted from: new discoveries (successful wildcats), delineation wells (generally adding to the size of the structure), deep tests (adding further pays), further testing of prospective formations above or below the Main Pay (which often not adequately evaluated), and from modelling and the occasional assessment of reserves with time.

These reserves figures allocate present reserves to the date of their discovery. Hence the sudden increase in reserves reflects the discovery of large fields, whereas the gentler build-up represents the addition of smaller ones, or fields which have not had much growth of reserves since their discovery date.

4.0 IPC and INOC Exploration Policy

There is a radical difference in the exploration policy of the concession era by the Iraq Petroleum Company (IPC) and the nationalised era by the Iraq National Oil Company (INOC).

Oil discoveries in Iraq have given prominence to the Cretaceous and Tertiary petroleum systems over others. The exploration search during the concession era was sporadic and limited. Only discovered fields with a high oil production rate in excess of some 5,000 barrels per day (bpd) per well were developed. The oil industry culture during the concession era was uniquely different since the rise of the national oil companies. I find it interesting to site an example of the old practices.

A number of structures drilled by the Iraq Petroleum company (IPC) and Associated Companies, proved oil/gas formation but produced a relatively low production rate (around 100 bpd on test) were classified unsuccessful and non commercial. Some formations in many exploration wells produced around 1,000 bpd, but the structures were left undeveloped.

Many tests were inconclusive due to technical problems and a few prospective reservoirs were by-passed (such as the Ratawi). Other oil reservoirs such as the Mishrif were not tested conclusively enough to be classified as commercial or not, and a few were not targeted (the Yamama in the south or the Lower Cretaceous prospects in the Zagros Folded Belt) on account of depth or other drilling problems.

Clearly the concept of what was commercial was influenced by the price of oil (then, around $1.0+ per bbl), the size of reserves in comparison to production commitment (R/P was never less than fifty since the discovery of Kirkuk field), and a host of other concessionary considerations and historically developed attitudes towards exploration and development. Invariably every discovered structure in Iraq has multiple reservoirs. The discovery of a good reservoir at shallow depth, such as Kirkuk oil field, with huge oil reserves appears to have precluded the early exploration of deeper prospects. The production system designed to handle the shallow reserves is not necessarily suitable to handle oil discovered later in deeper reservoirs.

A case in point is the early discovery of the prolific shallow Tertiary reservoir in Kirkuk. This had a great effect on the pattern of exploration in other areas, and the same or equivalent formations became the first objective for evaluation. The initial development of Bai Hassan and Jambur fields was for Tertiary production. It was 23 years before the first deep test (K-109) in Kirkuk oil field was drilled, which led to the discovery of oil in the Cretaceous formations, and in which oil was also found in Bai Hassan and Jambur. In these fields no Cretaceous pay was fully developed during the period of the IPC.

In the Mosul Petroleum Company (MPC) area north west Iraq, the Tertiary formations were found to be poor prospects, in which either heavy oil was discovered or low production rates were obtained, and drilling continued until reservoirs were penetrated in the Cretaceous at around 3000 meters and deeper. The main pays were then developed at Ain Zalah and Butmah in the Cretaceous reservoirs (the exception was one producing well from the Triassic in Butmah).

Likewise in the Basra Petroleum Company (BPC) area, the Tertiary was condemned when sporadic accumulations of heavy oil were found and the Cretaceous formations became a target. The development of Zubair and Rumaila fields was devoted almost entirely to production from the major reservoir (Zubair Formation) in each field.

The first well in Rumaila was drilled in 1953, following 25 wells in Zubair oil fields. The main productive reservoirs of the Zubair field were found to be present in Rumaila and after 1954 virtually all the development drilling was devoted to Rumaila: oil was found in other reservoirs in the Cretaceous, but they were not considered sufficiently attractive to divert effort from developing the Main Pay.

Only one reservoir deeper than the Main Pay was partially developed in Zubair (the Fourth Pay), and none of the others at shallower depth were developed, e.g. the Mishrif.

Because of the fact that a good producer in Kirkuk oil field produced some 100,000 bpd and a good producer in Rumaila some 50,000 bpd other discoveries where production was as low as 2,000 bpd or lower were naturally by-passed or capped and considered un-commercial.

The Iraq National Oil Company (INOC) as a government oil company adopted a different exploration philosophy. The assessment of the national hydrocarbon assets became an objective, and the race for production quotas among OPEC countries intensified the search for reserves. Geophysical activities and exploration drilling were increased. Assessment of other prospective formations (shallower or deeper than the Main Pay) became an objective in the discovered fields and in new structures.

The delay in appreciating the importance of the Cretaceous reservoirs and the almost total neglect of the Jurassic/Triassic reservoirs may be explained as follows.

The early discovery, in 1927, of the prolific shallow Tertiary reservoir in Kirkuk had a great effect on the pattern of exploration in other areas. The same or equivalent formations became the first objective. The first deep test in Kirkuk (K.109) was begun in

1951, 24 years after the initial discovery of Tertiary oil, which had in fact led to the discovery of oil in the Cretaceous, namely Shiranish, Qamchuga and Kometan limestone. For this reason the Cretaceous potential in the producing fields of the IPC area was not fully evaluated. In the MPC area, the Tertiary was found to be a poor prospect and drilling continued until reservoirs were penetrated in the Cretaceous.

Similarly, in the south the development of the fields Zubair and Rumaila was limited to the main pay zones of the Cretaceous. The full extent of the Tertiary reservoir formations and the many oil bearing Cretaceous reservoirs above and below the pay zones were not evaluated until recently by INOC.

With sufficient oil reserves from these major fields, even discoveries as important as Nahr Umr, Kifl, Rachi, Dujaila, Ratawi and Luhais were put on hold by the companies, as was the case with other giant structures, like East Baghdad and Buzurgan, which had been delineated by geophysical surveys.

Post nationalisation, exploration and development work by INOC in the south has given better appreciation of the oil-bearing reservoirs of Mishrif, Hartha and Nahr Umr, which are above the main pay zones, and of the deeper reservoirs of the Ratawi and Yamama which have become targets of a deep drilling programme.

No doubt the contribution of the oil reserves of these formations will add significantly to the up-grading of Iraq's reserves.

The Jurassic/Triassic contribution has thus far remained negligible. The evidence of its presence in the many locations in the north and extending to the southern and western areas of the country is yet to be appreciated. Apart from the conclusions of regional geological studies which give a high degree of prospectivity, there is ample drilling evidence which tested oil presence.

5.0 Reserves

Few definitions are given here by way of acquainting the non-technical readers and to denote their usage in the discussion that follows.

A reservoir is that portion of a trap which contains oil and/or gas as a single hydraulically-connected system. Although the hydrocarbons, *oil or gas in place are fixed quantities*, the *recoverable portion of the hydrocarbons in place (that is the reserves*) depends upon the reservoir characteristics and the method by which they are produced. *The ratio of the proven reserve to the oil in place is called* **recovery factor**.

5.1 Proven Reserves

The proven reserves define the recoverable oil from

reservoirs that are reasonably well delineated and have normally been in production long enough so that sufficient data becomes available to permit material balanced calculations to be applied, in order to achieve a greater degree of accuracy.

5.2 Semi Proven Reserves

Semi-proven reserves often refer to *the reserves of discovered reservoirs which have not been sufficiently delineated or put into production to permit calculations to the degree of accuracy obtainable in the case of proven reserves*. The reserves of such formations, for example, other than the main producing reservoir (although well delineated but not put in production) are sometimes also called Semi Proven.

5.3 Potential reserves

The potential reserves are the probable reserves that could be estimated from knowledge of past exploration history and knowledge of the geology of the basin under consideration. Again, reserves are meant to be the recoverable portion of hydrocarbons in place. The economics of finding and its development dictates the exploration effort in search for additional reserves.

5.4 Reserves Growth

The reserve estimate of any one reservoir improves with time as a result of further delineation of the reservoir's extent, the oil zone thickness and the recovery factor from better understanding of the recovery mechanism and sweep efficiency. Generally, reserve estimates made towards the latter part of the production history of the reservoir are much higher than those made during the early part, partly because of improved knowledge, partly because of professional attitudes which are conservative whilst dealing with uncertainties and, occasionally, because of policy reasons concerning market or political conditions.

The IPC's published reserves throughout the 1960s were based on conservative recovery factors, by and large, and semi-proven reserves were excluded.

As knowledge of the reservoirs advances with time, revision is justifiably introduced. In the case of the southern Iraq oil fields, for example, Zubair reserves of 1.9 B bbl and North Rumaila reserves of 5.0 B bbl of earlier years were increased to 4.5 B bbl and 8 B bbl respectively. Likewise, as knowledge of semi-proven reserves advances, their reserves may be upgraded and/or turned into proven reserves.

6.0 Estimate of Potential Oil Reserves

Potential reserves are estimated from knowledge of past exploration history and knowledge of the geology of the basin under consideration. Again, reserves are meant to be the recoverable portion of hydrocarbons in place.

I have made a few estimates for Iraq's proven and potential reserves over the last 45 years. The results are such as I must say I have good reason to believe in the richness of Iraq reserves and the figures given below quantifying them and that I would not be surprised if the future exploration would reveal much larger ultimate total reserves.

These are being covered below in chronological as follows:

6.1 INOC Founded in 1964

In 1966, under my supervision as the Executive Director in charge of the technical departments, the INOC geological and petroleum engineering departments, jointly with a credible team of American consultants from Frank Cole Engineering, carried out a study of potential oil reserves covering an area of approximately 215,000 sq km south of a horizontal line passing through the centre of the country near Baghdad and bound by the Iraqi boundaries from the south, east and west, but excluding the area surrounding the major producing fields of Rumaila and Zubair. Only 18 wells were drilled in the area. Ten found oil in commercial quantities and another two had encouraging shows.

A regional study of the area and the ME was carried out. Gravity, seismic and geological surveys from IPC records were interpreted and structural anomalies derived.

301 structural anomalies were derived, of which only 135 were considered highly credible to produce oil, based on the study of new field wildcat success of 50% in this same general geological province of the ME during the period of 1949-1963.

An estimate of potential reserves was made from the total number of structures and volume of potentially petroliferous sediments multiplied by a recovery factor and a success ratio. The recovery factor was based on analogy with other discovered and produced reservoirs in Iraq. The success ratio was obtained from past exploration performance in the basin. The integrity of the structures was based on the results of weighing the stratigraphical, geological and geophysical data.

In these 135 anomalies alone the potential oil in place, in a part of the Cretaceous age formation, was conservatively estimated to be in the order of 390 B bbl and the potential recoverable oil was estimated to be in the order of 111 B bbl.

6.2 Independent Consultant in 1994

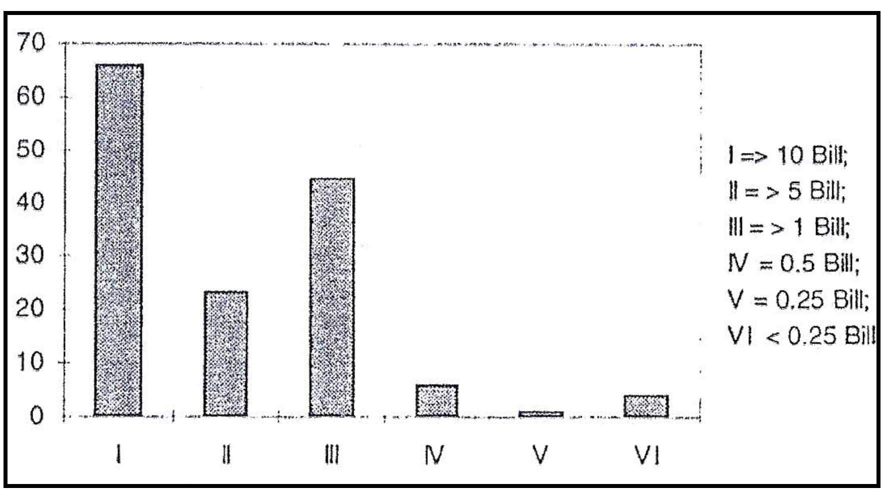
In 1994, I presented a paper at a geological oil conference in Amman, Jordan, and developed it further a year later for an oil conference at the Centre for Global Energy Studies (CGES) in London.

The paucity of published data (traps, plays and related geology, seismic, gravity, etc.) makes it difficult to make anything other than an estimation of the order of magnitude of Iraq's potential oil reserves. The approach adopted in this paper makes use of the empirical relationship between exploration and reserves build-up, where exploration effectiveness starts low at the initial phase, picks up sharply, grows linearly until the major part of the oil deposits are discovered, and then slows down as the ultimate reserves of the basin are approached.

I utilized an empirical relationship which relates the discovered oil in a geological basin to the exploration effort along a time-scale. It demonstrates that exploration effectiveness starts low at the initial phase, then picks up sharply and grows almost linearly until the bulk of the reserves are discovered, when it slows down as the ultimate reserves of the basin are reached.

An 'S' shaped curve resembles the relationship between cumulative discovered reserves and time or exploration effort, which lends itself to statistical and mathematical calculations, making use of log-Normal and Yule distribution functions.

With the aid of success ratios and the table below I successfully forecasted Iraq's reserves in 1994 & 5.



In Iraq, there are some 530 structural anomalies that have been identified by geophysical means. Of these, only 114 have been drilled and, by 1994, oil was established in 73 structural anomalies. I estimated the total ultimate oil reserves housed in these 73 anomalies to be in the order of 144 B bbl, which is in conformity with published data and the experience of Iraqi experts.

With the use of size distribution and varying success ratios, the potential oil reserve was estimated to be in the order of 280 B bbl to 360 B bbl, housed in 143 to 183 structural anomalies.

Based on the distribution and total reserves to date shown in the above table, future potential oil reserves are estimated to be of the order of 280 to 360 B bbl, to be found in 143 to 183 additional oil fields out of the total remaining structures.

Of the 416 remaining structures only 286 (69%) were considered to have sufficient integrity to justify their acceptance. To these the overall success rate (per structure) 64% and the lower success rate (per wildcat) of 50% were applied.

The lower limit of 143 fields, giving rise to 280 B bbl, is based on a success rate of 50%. The upper limit of 183 oil fields, giving rise to 360 B bbl, is based on an overall success rate of 64%, derived from an overall past exploration and drilling of 114 structures, producing 73 successful discoveries.

These average success rates should have a good chance of being maintained, since they actually fall below the success rate of 73% for the more recent discoveries made in the period 1970 to 1989, referred to in the preceding section.

The use of a 50% success rate implies that the latest success rate of 73% would have to decrease to 27% towards the end of the projected exploration time.

The degree of confidence, in the above result may be examined in the light of the facts mentioned above, and summarised below, along with other evidence which I gave at the time are as follows:

⇒ 78%, (416 of 530), of delineated structures remain unexplored. The success rate in locating oil in the period 1970 to 1989 was 73% (38 of 52), which represents an improvement over and above the overall success rate of 64% (73 of 114). This indicate that the discoveries thus far should fall at the lower sector of the "straight line" section, justifying linear projection of the "S" curve relationship relating oil field discoveries to exploration effort.

⇒ The reserves in many of the discovered fields have yet to be increased to reflect the evidence of reserves in multiple reservoirs that have been established in the Tertiary and Cretaceous, in both the new and the known discoveries in the south, thus giving rise to a higher total reserve than the estimate of 144 B bbl and, thus, to a higher average reserves per discovered field. In other words, the reserve per category could very well increase as delineation work of the new fields proceeds and further development and evaluation of new discoveries and producing fields advances.

⇒ The revaluation work and further drilling for the Cretaceous deposits lying below the known reservoirs in the north-east will add further oil reserves, ignored in the past.

⇒ The Jurassic/Triassic promising prospects in the locations already drilled in the north, south and south-west have yet to be evaluated and further exploration wells yet to be drilled, particularly in the area west and south of the Euphrates, which has already proved its prospective quality.

⇒ The many possibilities existing for stratigraphic traps have not been explored as yet.

⇒ Many structures, particularly in the north, have been condemned by the IPC and/or MPC either as dry or as containing gas or bitumen. No doubt some of these would have to be re-explored to prove them dry or successful.

⇒ The discovery of Paleozoic oil in Saudi Arabia, the Akkaz field in the western sector of Iraq and the presence of a large number of delineated structural anomalies there, make the Western Desert a Paleozoic hydrocarbon province whose potential and reserves are yet to be evaluated.

The above stipulation is valid today as it was in the past

6.3 P&A Study of 1997

This is the more detailed and comprehensive study which took 3.25 man-years by a team of 7 geologists, petroleum engineer and a mathematician.

In a joint study with CGES on Iraq's Exploration Potential and Production Capacity in 1996 -1997, the P&A team, involving myself as coordinator and principal researcher and associates from amongst the most experienced petroleum engineers and geologists, carried out an a 4-volume comprehensive study. It covered Iraq's proven and potential reserves.

The proven oil reserves were estimated at 128 B bbl, housed in 80 fields, of which 124 B bbl were housed in 43 discovered fields. The remaining 37 fields were discovered but not sufficiently delineated or produced. Each had been assigned only 0.1 B bbl. No doubt their reserves will appreciate when developed.

Iraq's potential reserves were estimated conservatively to be in excess of 216 B bbl. These are many large fields with as much reserves as in some of the discovered giant fields. The largest eight potential fields housed some 50 B bbl, compared with 92 B bbl housed in eight discovered fields.

Gravity, seismic and geological surveys enabled preliminary estimates of the volume of sedimentary rocks. Estimates of potential reserves were obtained from the total number of structures and volume of potentially petroliferous sediments multiplied by a recovery factor and a success ratio. The recovery factor was based on analogy with factors from other discovered and produced reservoirs in the basin. The success ratio was obtained from past exploration performance in the basin. The integrity of the structures was based on the results of weighing the geochemical, stratigraphical, geological and geophysical data. Throughout conservative reserves estimate parameters had been adapted which are given below.

P&A. Reservoirs and Oil Parameters

Formation	Porosity	SW	Recovery	FVF
Jeribe+	0.22	0.15	0.30	1.20
Shiranish	0.01	0.00	0.90	1.31
Hartha	0.24	0.18	0.25	1.31
Khasib/Sadi	0.24	0.18	0.25	1.31
Mishrif	0.22	0.28	0.25	1.34
Mauddud	0.18	0.20	0.30	1.25
Nahr Umr	0.20	0.25	0.30	1.25
Zubair	0.24	0.19	0.40	1.35
Yamama	0.19	0.16	0.30	1.43
Najmah	0.15	0.17	0.25	1.43
Kurra Chine+	0.15	0.20	0.25	1.55
Akkas	0.17	0.20	0.25	1.55

Our estimate was based on conservative volumetric calculations, using average porosity, oil shrinkage and a recovery factor not exceeding 31% for the oil reserves recoverable from 224 anomalies, among the total of 440 surface and sub-surface identified anomalies which are sufficiently prospected to be included. The potential proven reserve was estimated at 455 B bbl, to which a success rate of 47.5% was applied (being the average of 70% terminating at 25% at the end of the exploration period), giving 216 B bbl of proven reserves.

- **Methodology and Results**

According to Iraqi semi-official publications there are 530 structural anomalies and leads, of which 239 are considered to have a high degree of certainty (some 70%), which are yet to be drilled.

Our study has identified around 440 surface structures and subsurface structural anomalies, identified from personal experience, geological maps and geophysical data. Around 40 structures are located in the High Folded Zone, a difficult mountainous area in which very little geological work has been undertaken. On further scrutiny and to err on the conservative side, a further major reduction brings the total to 231 anomalies. These are made up of 118 undrilled anomalies, in addition to the 113 anomalies which have been drilled, of which the majority, 106 anomalies, have prospective formations at their location. This brings the prospective anomalies with undiscovered reserves to 224.

- **Main Reservoir Pays**

P&A. Main Reservoir Pays

Age	Reservoir	Fields
Tertiary:	Asmari	Buzurgan, Jabal Fauqi.
	Jeribe	Abu Ghirab.
Cretaceous:	Hartha	Majnoon, Balad, Falluja.
	Sadi	Majnoon.
	Tanuma	East Baghdad, Balad.
	Khasib	East Baghdad, Majnoon, Balad, Tikrit.
	Mishrif	Rumaila South & North, West Qurna, Zubair, Tuba, Buzurgan, Jabal Fauqi, Majnoon, Abu Ghirab, Halfaya, Abu Amud, Ahdab, Gharraf, Amara, Noor, Dujaila, Nasiriya.
	Rumaila	East Baghdad, Rumaila.
	Ahmadi	Majnoon.
	Mauddud	Majnoon, Abu Amud, Gharraf, Badra.
	Nahr Umr	Nahr Umr, Majnoon, East Baghdad, Halfaya, Safwan, Tuba, Abu Amud, Gharraf, Nasiriya.
	Zubair	Rumaila South & North, West Qurna, Zubair, Safwan, Rachi, Tuba, East Baghdad, Buzurgan, Nasiriya, Siba, Kifl, Subba.
	Yamama	Rumaila, Ratawi, Amara.
Jurassic:	Najma/Gotnia	Luhais, Samawa, Rumaila, Falluja.
Triassic:	Alan	Samawa.

The above table shows a number of significant reservoirs and discovered fields in the central and southern areas of the country. Each oil field is given its pay/s, reservoir, and geological age.

The production capacity per well for any one reservoir pay is preliminary in nature, often quoted from initial tests which have neither been treated for enhancement or produced for sufficient production life to confirm its credibility.

Clearly, the production rates for the new reservoirs are tentative, but low production rates are well established in most fields and for almost all the new reservoirs reviewed above. Apart from the Cretaceous Zubair sandstone of the Rumaila South field, where the average production rate per well is some 15,000 to 20,000 bpd (and to a lesser degree the Zubair field with 4,000-5,000 bpd), typical rates elsewhere in the new fields further away from the Zubair and Rumaila fields, are only some 10% of the above high rate Zubair sandstone. The newly discovered fields in the south, southeast and central areas give low production rates from newly developed reservoirs, as shown in the table below.

P&A. Pays & Production Rate Per Well

Reservoir	Fields	Production Rate Per Well, BOPD
Jeribe/Asmari	Abu Ghirab	1,500
	Buzurgan	2,000
Tanuma/Khasib	East Baghdad	500-700
Mishrif	Zubair	1,500
	Rumaila South	1,500
	Luhais	1,500
	Abu Ghirab	1,500
	Rumaila North	700
	West Qurna	700
Nahr Umr	Nahr Umr	2,000
	Halfaya	1,500
Zubair	Rumaila South	20,000
	Zubair	4,000-5,000
	Subba	2,000
	East Baghdad	1,500
	Tuba	1,000
Yamama	Ratawi	2,000-5,000
	Amara	2,000-3,000
Najmah	Luhais	1,500

- **Reserves of Reservoir Formations**

P&A. Potential Reserves at 100% Success

Formation	Age	Reserves (B bbl)
Jeribe+	Oligocene & Lower Miocene	41.58
Shiranish	Upper Cretaceous	14.92
Hartha	Upper Cretaceous	32.75
Khasib/Sadi	Upper Cretaceous	20.75
Mishrif	Upper Cretaceous	4.33
Mauddud	Upper Cretaceous	42.35
Nahr Umr	Upper Cretaceous	24.33
Zubair	Lower Cretaceous	67.19
Yamama	Lower Cretaceous	50.83
Najmah	Lower Cretaceous	77.68
Kurra Chine+	Jurassic/Upper Triassic	62.72
Akkas	Paleozoic	15.48
Total		**454.89**

Potential Reserves by formation breakdown are given in the table above. These yet to be discovered potential reserves appear to be in the following descending order:

Najmah, Zubair, Kura Chin, Yamama, Mauddud, Jeribi+, Hartha, Nahr Umr, Khasib/Sadi, Akkas, Shiranish and finally Mishrif as shown in the above table for Potential Reserves.

The reserves of the Mishrif have proved much larger as a result to the oil presence covering much more extensive area than previously assumed and the use of higher recovery factor.

The total ultimate undiscovered potential reserves are thus 455 B bbl of oil. This estimate was, however, based on an exploration success of 100%. Accepting that the high initial success ratio of 70%, which has been the norm in Iraq will decrease with time to a conservative cut off level of 25%, the average success ratio of 47.5% during the remaining exploration period, gives an ultimate undiscovered reserves of 216 B bbl. The undiscovered reserve per drilled anomaly of about 1.0 B bbl is of the same order of magnitude, if slightly smaller, than the 1.2 B bbl for discoveries to-date. The study *indicates that there are super giant fields, the largest of which could be comparable to the super giant Kirkuk or Rumaila fields. However, the distribution is more even than the oil discovered so far, since the first eight fields of undiscovered reserves represent about 23% of total undiscovered reserves,* while the comparable figure for discovered reserves is higher than 70%. *They show a significant number of giant fields, with some 30 structures, each with more than 2 B bbl of recoverable reserves, with an average of just under 4 B bbl each.*

With access to a substantial database on Iraq, INOC estimated a 212 B bbl of oil yet to be discovered, which is remarkably close to the estimate obtained in this study. Without more information on the details of their calculations it is difficult to compare the two results, but it seems that we have fewer anomalies on which future discoveries are to be made, while our average discoveries are larger.

An attempt was made to use a probabilistic approach to estimate undiscovered reserves, but a deterministic approach was finally accepted to be more appropriate, taking into consideration the data available and the scope of the study. The size distribution of reserves in Iraq shows typical log-normal distribution. An examination was carried out of the distribution of all Iraqi ultimate and potential reserves.

6.4 Exploration (Finding) Cost and Potential Reserves

The table below gives the Finding Cost, 1997 $

BPC	**0.1 cents/bbl**
IPC	**0.35 cents/bbl**
MPC	**5.6 cents/bbl**
Iraq (overall)	**0.26 cents/bbl**

The drilling costs for the IPC and Associated Companies to 1960 and for INOC to 1980 are analysed and plotted according to cost per foot vs. depth, on a semi-log graph, to facilitate cost estimates for exploration wells to the desired depth in the absence of known well costs. For the IPC and INOC periods, the assessed cost for an exploration well is $1.1 MM and $2.3 MM respectively. Pre-geophysical, geological and overhead costs are estimated at 50%, giving a total cost of $1.65 MM and $3.5 MM. *Dividing these costs by their respective discovered reserves gives a weighted exploration intensity of 0.32 cents per barrel (cents/bbl).*

The IPC and Associated Companies' accounts provided another estimate which is comparable to the above. The exploration cost (intangible assets) given in the IPC accounts for each company was adjusted to reflect the replacement value at the end of 1960 and then to 1997 by the use of appropriate inflation indices.

The exploration costs so derived for each company amounted to $43.59 MM (BPC), $88.2 MM (IPC) and $16.08 MM (MPC). Dividing their total cost by the discovered reserves would give a comparable, less if any, cost to the above; a fraction of a US Cent.

Today, with exploration success of 70% being maintained, the Finding Cost would very well be a fraction of a Dollar.

- **How will this affect the exploration for Potential Oil Reserves?**

Since the finding cost, as highlighted above, is under One US Cent or only a fraction of a US dollar per bbl associated with a discovery success of 70%, surely *it should be economically prudent to intensify exploration and sustain it to a much lower cut-of level than the one assumed in our study, as long as the finding cost remains within acceptable range, particularly in view of the prevailing oil prices. Thus the potential reserves would be larger than estimated above.*

Almost half of the anomalies have been eliminated. Only *the simplest of traps have been considered,* the simple structure being a reflection, no doubt, of the prolific nature of the oil industry in the ME. No doubt, *the time will come when it becomes necessary and profitable to look into more complicated traps, such as stratigraphic traps.*

6.5 Proven Reserves

The published proven reserves figure from semi-official sources stood at 112 B bbl during 1997 when our P&A study was carried out. The reserves were distributed (according to the same sources) in 73 fields, 9 of which are super giant or giant fields (Kirkuk, South Rumaila, North Rumaila, West Qurnah, Zubair, Majnoon, Nahr Umr, Halfaya, and East Baghdad) and 22 are large fields.

Age-wise, the reserves comprise:

23.9% Tertiary,

76% Cretaceous and only

0.1% Jurassic/Triassic.

Our estimate, based on 'best judgement' of ultimate reserves assigned to each individual field or discovery, provides a total Ultimate reserves figure of 125 B bbl, housed in 79 fields.

According to our study of 1997, the distribution of the reserves by age is given below and shown and in the graphical form which follows.

23% Tertiary,

73% Cretaceous, and

4% Jurassic/Triassic.

Our field by field reserve estimate referred to above was based on a review of reported reserves by specialised sources (OGJ, WO, MEES, etc.), the Iraqi Oil Ministry News Journals, OAPEC Country Reports and leading authors. These were examined against relevant information such as the field's historical production profile or announced plans. In-house experience and personal enquiries came into play in arriving at 'best judgement' reserve figures assigned to these fields.

Our ultimate reserve was then estimated at 125 B bbl. It gives a present (1997) proven (remaining) reserve figure of 101 B bbl, which is sufficiently close to BP statistical review of remaining reserves figure for Iraq of 100 B bbl at that time in 1996-1997. Our estimate, however, included 37 discovered fields, assigned only 0.1 B bbl per field. Many of these have since been considered for development. One would expect a considerable number of them to prove to hold substantially larger reserves.

A recovery factor as low as 31% was used when 35% had been assessed as a global average by BP a decade ago. With a crude oil price floor around US $ 50 and a near future of over $ 100 and present Iraq capital investment cost, CAPEX, of $ 1.5-2.5, additional secondary recovery cost would permit higher reserves recovery.

6.6 Iraq's Oil Resource Base

A comparison of the present reserves with the potential, which make up the resource base, is given in the table shown below.

Age	Discovered Reserves		Potential (undiscovered) Reserves	
	B bbl	%	B bbl	%
Tertiary	27.2	22.8	19.6	9.1
Cretaceous	87.6	73.3	159.2	73.7
Pre-Cretaceous:	4.7	3.9	37.1	17.2
i. Jurassic/Triassic	-	-	29.8	13.8
ii. Paleozoic	-	-	7.3	3.4
Total	119.5*	100%	216	100%

Iraq's oil reserves have stood at 115 until last month in November when the Ministry of Oil (MoO) announced a revision to 143.5 while the potential reserves stood at an estimate of around 215 B bbl, which is in line with the only study of the MoO's at 212 B bbl and our P&A's of proven reserves at 120 and 216 B bbl in the 1997 study.

The Tertiary reserves will add some 19.6 B bbl, the Cretaceous some 159.2 and maintain its high share of the total, the Pre-Cretaceous some 37.1 and increase its share of the total.

It is anticipated, however, that the *Pre-Cretaceous will at least be double the estimate here,* since during the time of our study in 1997 there has been no seismic or exploration drilling carried out, while recently much exploration has been carried out, in the north east uncovering substantial amounts of reserves.

6.7 Iraq Latest Reserves Increase

The MoO, in their latest announcement of last month, considers 34% recovery is applicable to 66 Upgraded Fields. *Iraq reserves has been revised to 143.1 B bbl. Supergiant West Qurna Field recovery rate now 42%, giving it 43.3 B bbl and supergiant Kirkuk Field has highest recovery factor 58%*. And complex fields at around 15%. The bulk of the increases reserves came from West Qurna, where the reserves were doubled to 43.3 B bbl. Past practice limited the recovery to 15-31% for most of the fields with the exception of Kirkuk and Rumaila which were given a higher recovery factor.

Iran used small increases across various fields to justify its modest jump to 150.3 B bbl from 138 B bbl in a hurry to b eat Iraq. It has been reported that Iran uses an average recovery rate of 20-25% to calculate its reserves. This, indeed, assumes very conservative estimates, though may prove to be generous for newer fields, like Azadegan where the likely figure may be around 10-15%, judged by the generality of its oil and reservoir characteristics.

Saudi Oil Minister Ali Naimi addressed the issue recently, saying, “Initially when a field is discovered, they say ‘We can recover 17%’ because they don’t have any experience with producing that field. As time goes by and they drill more wells and see the reaction of the reservoirs, they say, ‘Well, I think we can recover 35%.’ And finally the average that the industry believes can be done is about 50%, and 50% to 60% at fields like Ghawar are within reach.”

BP had achieved 50% over a decade ago in the North Sea, and 60% had been achieved but sparingly in the North Sea and elsewhere. The industry target is 70% and above.

However, to extract oil from the very marginal fields, oil prices above the present floor of $ 40-50 per barrel would have to support capital costs at a higher level than currently prevail.

6.8 Conclusion: Iraq’s Reserves

- *While recovery rates, higher than previously in Iraq, should prove fairly likely, however, this can be justified and demand respect following future production observations of sweep efficiency and relevant reservoir parameters with aid of 3D seismic surveys, oil/water and oil/gas contact levels, subsurface pressure are examples which enable material balance calculations be made to ascertain its validity.*

- *Uncalled for conservatism in estimating reserves can be as costly as in pessimistic estimates. The cost of oversized production infrastructure beyond the fields’ boundaries to the export flange (such as transfer lines, storage tanks and terminals) becomes a waste of capital investment and so is the case under-designed capacity. The latter is just as costly it eventually requires additional capital investment with a loss of the economies of scale.*

- *Iraq’s use of recovery rates below global averages accounts, in part, for Iraq’s past adoption of outdated technology and mal-production practices during the periods of the Gulf Wars, sanction years and during the present time, since 2003. Kurkuk and Rumaila had their share of potential damage.*

- *Iraq's 441,840 sq km is almost entirely underlain by Silurian and/or Jrassic and Cretaceous rich, sufficiently mature source rocks and sparsely drilled by one* *exploratory well per 2900 sq km. Roughly, one third of area virgin, one third scantly explored; one third unexplored. Iraq is the least explored major hydrocarbon resource basin in the Middle East. Large parts of the country are still virgin with huge untapped resources*

- *In house re-interpretation of seismic at the present time using the latest computerised software indicates the presence of large number of stratigraphic traps and many more structural anomalies than the delineated 530. The new identified stratigraphic traps and structural anomalies, remaining identified undrilled ones, the untested shows, the many discovered fields especially those in the south which are yet to be tested for their deeper horizons (L. Cretaceous, Jurassic and Triassic), and Jurassic/Triassic oil reserves in the relatively virgin Western Desert and the Folded Zone along the Zagros belt, will no doubt increase Iraq oil reserves to or even beyond the above estimates.*

  By way of an example, exploration of the in Iraq Kurdistan has given estimate reserves in excess of 40 B bbl and an exploration success in line with Iraq overall average of 70%. Neither the fields' proven reserves nor the potential has been included in the above estimated reserves.

- ***On the basis of the above studies, potential reserve growth from future discoveries and likely future enhanced recovery of Iraq's oil, the present estimates of proven reserve of 115 B bbl and a potential reserve in excess of 216 B bbl should prove fairly certain with a high probability to be exceeded. The total present Iraq's oil resource base of 331B bbl assumed at 31% recovery, an improvement by 15% (well within the future art of technology and Saudi present achieved recovery) would make Iraq resource on par with Saudi Arabia's, if not higher.***

7.0 Can Iraq Achieve the Anticipated Production of 12 mbpd?

At an annual depletion rate (Production/Reserves, P/R) of 4-5%, Iraq can continue its upward production rate to 10 mbpd and beyond to 12 mbpd conditional on, in the case of the latter rate, adding new potential reserves so as not to exceed the above depletion rate.

While developing 10 mbpd is achievable within good oil industry practice of allowing an annual depletion rate of 4-5%, with no exploration, the results are not as robust, but still robust enough.

Production capacity is a function of the remaining recoverable reserves, potential reserves and the rate at which the latter are discovered.

Production from an oil field or a group of fields takes a 'bell shaped' curve sometimes referred to as the "Hubert curve"; a symmetrical curve whose peak is followed by an exponential decline.

Building Iraq's current production rate to a peak of 10 mbpd and maintaining the plateau for 8 years would require a P/R of 4% at the beginning, rising to 5.3%, when it is allowed to decline. At the end of 25 years the production rate would be 6.4 mbpd, but the reserves would have declined to some 42 Bbbl, from 115 Bbbl at the start of the build-up.

To build-up 12 mbpd and maintain P/R at 4% to 5%, would require additional reserves to supplement the current 115 Bbbl remaining reserves. In this case, additional reserves of 3 Bbbl per year need to be added, starting from the 7th year. The plateau is maintained for 8 years as the remaining reserves decline to 98 Bbbl. By the end of the 25th year, the production rate is 11 mbpd and the remaining reserves are 91 Bbbl, with the P/R being kept within the desirable depletion. A total of 57 Bbbl from new discoveries have to be added, which represents only 26% of Iraq's likely potential reserves.

The production rate at the end of the 25 years is still a healthy 6.4 million bpd, and the remaining reserves at that time some 48 B bbl.

12 mbpd requires additional total reserves of 57 B bbl, which is fairly feasible to be added at an advanced stage of development at an annual rate of 3 mbpd, to ensure sustaining a healthy depletion rate at 4-5%.

And, conservation of reservoir energy, optimum reserves recovery at least cost can be at risk if and when the highest production plateau is pre-determined, as the case in Iraq's contracts, which ignores the uncertainty associated with pre-judging its level. There is an intrinsic relationship between depletion rate of reserves and recovery. A balance between the two can only be obtained by development in stages while observing and evaluating reservoir reaction.

Iraq oil service contracts commit some 83B bbl to attain a plateau of 12 mbpd. This requires higher depletion rate than 5% which could well risk achieving less than the optimum recovery and would likely be at a higher unit cost. Therefore, the oil production plateau and its targeted duration stipulated in Iraq's contracts ought to be complemented not only by the anticipated enhanced recovery but also by additional reserves from within and/or without the contracted fields.

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