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World Petroleum Resources — where, why, and how much?

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Abstract: With some confidence, we are now in a position to estimate the location, geologic rationale, and general quantities of the world petroleum resources. Clearly, the last barrel has not been discovered, but the broad geologic factors that control large occurrences are recognized and incorporated into an hypothesis of Petroleum Realms which recognizes three broad regions of the world (Boreal, Tethyan, and South Gondwana — from north to south), wherein climate conditions, over geologic time, controlled the quality of source rock, the presence or absence of carbonate reservoir rock, and the existence of salt seals. Because South Gondwana has experienced such low latitude conditions since post Jurassic time, it is poorly endowed with petroleum resources. A fourth Petroleum Realm, the Pacific Realm, likewise is poorly endowed with petroleum resources but for reasons of tectonism and volcanic activity. As an outgrowth of these controlling geological/climatic conditions, combined with analyses of exploration history and estimates of Undiscovered Resources, we would propose that, by the year 2010, more than 50% of the world's oil will be produced by OPEC, up from 33% in 1990.

INTRODUCTION

As US Government geologists, pursuing the subject of world energy resources, our role has been to address the geological limits on supply, but, in this world of constantly changing technology and scientific understanding, any pronouncement on petroleum occurrence is necessarily dated. We are well aware that attempts to divine the future or to know absolute truth commonly fall short, but we reason that to have studied an area and formed a geologic and resource quantity opinion puts us in a position to recognize anomalies as they occur and enables us, periodically, to adjust the big picture — basin or area at a time.

We think of our resource assessment work as presenting a numerical hypothesis of the petroleum resource condition of the earth. We publish the various elements of our geologic findings, which is the supporting evidence for our hypotheses, and periodically we bring it all together to advise the US Government and the scientific community of the present realities. Scientifically, our task becomes one of challenging those hypotheses, that is the quantitative resource assessments, as well as trying to derive different ways of expressing the significance and the consequences of the petroleum resource conditions we believe exist. In this paper, we show our latest aggregation of assessment findings but also express the continued weakness in the analysis of Reserves — those values we used to think we understood with only a minimum range of error. Secondly, I want to review the distribution of the estimated quantities of conventional oil and gas and suggest physical scenarios for the production of oil that could derive from those resources, as well as to emphasize the role natural gas could play in offsetting the growing distributional imbalance of oil resources. And, finally, I want to express what we think we understand about the underlying reasons for this distributional imbalance of petroleum resources; it is the confidence in this reasoning, relative to distribution, that has led us to conclude that, though there still is a significant amount of oil and gas to be discovered and developed, we believe the geographic distribution of the resources has been established and the world society will have to adjust to that reality and to its consequences.

PETROLEUM RESOURCES

The numerical results of our studies (Masters *et al.*, 1990) are shown in Figs. 1 and 2. Both figures are arranged in the same fashion with cumulative production and identified reserves shown in the bar graphs on the bottom and undiscovered resources, displayed on probability curves, shown in the upper part of the figures. With respect to the Undiscovered Resources, we consider there to be a most likely or modal probability for the future occurrence of 489 BB (billion barrels) of oil. And for gas, the most likely value of the undiscovered resources is 4,417 TCF (trillion cubic feet). In comparing these two resource graphics, note that the ultimate amount estimated for the two resources, i.e., the sum total of cumulative Production, Reserves, and Undiscovered

Resources, is approximately the same with there being slightly more recoverable oil estimated — 2171 BB — than BTU (British Thermal Units) equivalent gas — or 1752 BBOE (billion barrels oil equivalent). As discussed below, however, we believe gas to be underestimated owing to data limitations deriving from immature market exposure. As gas becomes more mature in its development, we expect the estimates of the Ultimate Resources of gas to increase up to the general level of oil — but not to exceed oil in any substantive way. Keep in mind, with respect to these numbers, that we are assessing conventional oil and gas as we now define it. Certainly, technological breakthroughs could require reevaluations. Another point to consider is that exploration and development for oil is significantly more mature than it is for gas — 80% of the assessed Ultimate Resources of oil has already been discovered, whereas only 60% of the gas has been discovered.

Discovery-Production

Annual discoveries of oil averaged over 5-year periods as compared to annual production as shown by the crossing white line in the bar graph (Fig. 3). The different shades on the bars refer to selected world areas. We know the general reasons for the production variations. Clearly, an abrupt decrease in demand followed the early 1970's price adjustment; again, at the turn of the decade, a second price doubling caused the consumer to retreat for a few years, but we are now on a general upturn, and who can say what combination of factors will affect or control that demand? This graphic also tends to support our understanding of maturity in oil development. The really big days of exploration and development are behind us. In the last 10 years, discovery has fallen below production and, while we expect field growth over time to increase these values, we do not anticipate that they will result in discovery exceeding production in any significant way. So, with the general rate of discovery being less than 20 BBO/yr (billion barrels of oil per year), we anticipate only a few more decades of significant amounts of additions to reserves. In addition, a strong limiting factor is the ability of the industry to actually discover the estimated resources. Rightly or wrongly, we have assessed a very large potential range of undiscovered oil resources — 300-1,000 BB. At the present discovery rate of less than 20 BBO per year, and declining, there is a clear challenge to the expertise of the explorer.

The discovery production history for natural gas is shown in Figure 4, constructed the same as for oil. Generally speaking, one might expect a
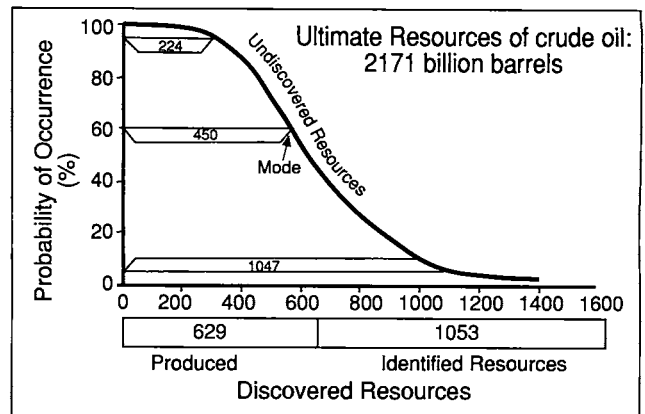

Figure 1. Ultimate Resources of crude oil in terms of Cumulative Production, Identified Reserves, and Undiscovered Resources.
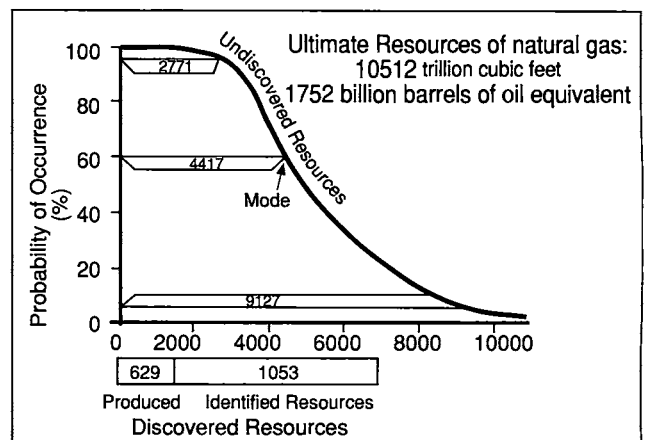

Figure 2. Ultimate Resources of natural gas in terms of Cumulative Production, Identified Reserves, and Undiscovered Resources.

similar interpretation of its variables, but with gas being less maturely exploited than oil, there are likely to be some surprises which defy projection. Recent large discoveries in the Kara Sea and the Barents Sea of Russia will increase the most recent five-year average to a level above 100 TCF per year which is higher than present production. Those discoveries were expectable events, and we can visualize their being repeated, so historic declining discovery in no way reflects the strength of the gas resource base.

Reserves Growth

As noted above, we expect an increase in the Ultimate Resources of natural gas as soon as we gain a better understanding of gas reserves through improved reserves-growth information. The change in our Reserves perception over the past four years — a sharp increase is shown in Figure 5. Normally, one would consider that such a positive change reflects discovery substantially in excess of
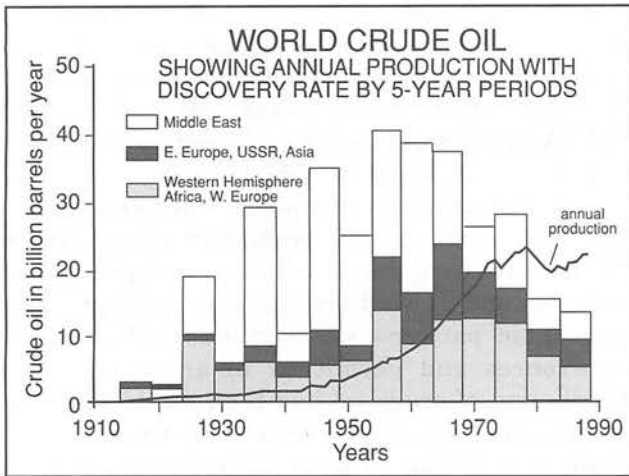
Figure 4. World natural gas annual production and discovery rate, the latter averaged over 5-year periods.
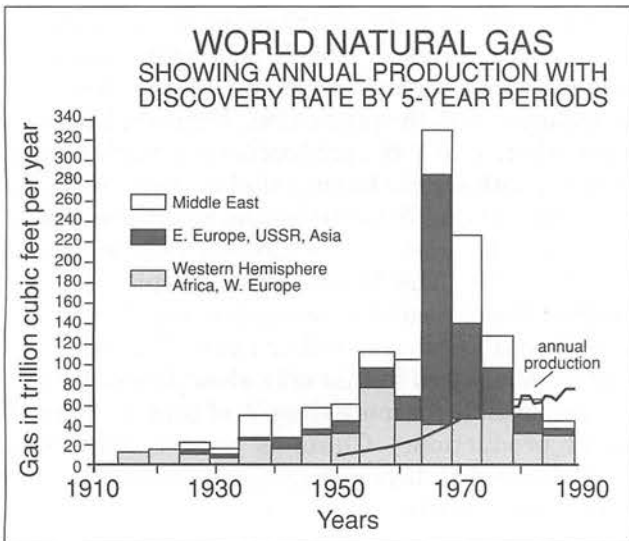

Figure 3. World crude oil annual production and discovery rate, the latter averaged over five-year periods.

production. To the contrary, however, the data shows that, for two recent 5-year periods, production has been in excess of discovery. The answer to the dilemma is field growth — that is, the reserves growth, over time, of already discovered fields. Similar graphics would show the same conditions with respect to oil. In order to capture this growth variable in resource work, we try to report an Identified Reserve — a reserve value which includes Probable Reserves and Possible Reserves in addition to traditional Proved Reserve. In other words, the Identified Reserve attempts to estimate the quantity of all the reserves that will be produced from a field or group of fields, not just the amount that is economically producible at any one time.

Resource Distribution

The distribution of the Ultimate Resources of oil and gas by world regions is shown in Figures 6 and 7. Cumulative production is shown at the top with Identified Reserves and Undiscovered Resources making up the remainder of each column. The distribution of the world's oil and gas is uneven. Our count shows that 74% of the world's oil and gas resources occurs in just three geographic areas, North America, Middle East, and the former Soviet Union. And the oil and gas are concentrated in just a small part of those three vast regions. With respect to oil, the Middle East is overwhelmingly dominant. Taken together, however, the other four regions of the globe, South America, the Far East, Africa, and Europe, constitute a significant minority of production, but this can be sustained for only a few decades.

Gas distribution is slightly different (Fig. 7). Here, the former Soviet Union dominates, with
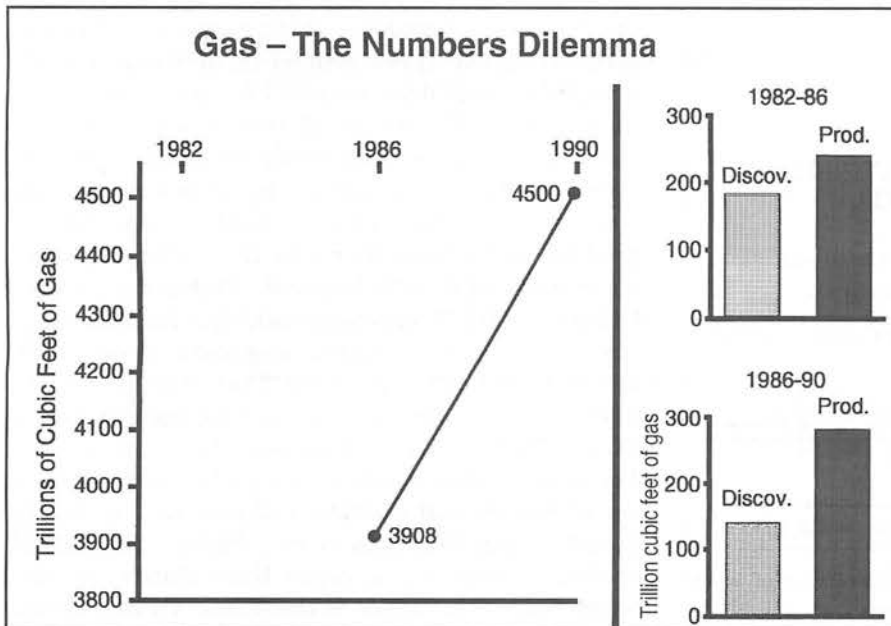

Figure 5. Shows the numbers dilemma of natural gas with sharply-increased reserves values, over time, matched against two 5-year records of production in excess of discovery. Reserves growth of existing fields explains the dilemma.

respect to the big three, but the dominance is not so extreme for oil. What stands out is the imbalance of production/consumption. Only in North America has gas been used extensively. Clearly, the Russians are moving to catch up and they have an enormous gas resource that, in fact, could enable them to completely substitute for whatever decline in oil production might occur — but change costs money.

RESOURCE PRODUCTION

General

The other great marketing issue is what will the Middle East do with its vast under-used gas resource — compete with oil? It is difficult to believe they would do so, but Qatar, with North Dome, the largest gas field in the world, would also like to make money. What about the rest of the world and its modestly used gas resource? Will it provide local energy or will it export to overseas markets, such as in the US? The sparring on all of

Figure 6. Distribution of the Ultimate Resources of world crude oil by seven geographic regions.

Figure 7. Distribution of Ultimate Resources of world natural gas by seven geographic regions.

these fronts is just getting seriously underway. A major project to watch, in this regard, is the Cristobal Colon project, offshore NE Venezuela and Trinidad, where Shell, Exxon, Mitsubishi, and PDVSA are evaluating an LNG project scheduled to go on line in the late 1990's.

The remainder of this paper will focus on two points: 1) What are the production ramifications which derive from this distribution and quantity of crude oil, and 2) what are the broad geologic, and geographic patterns which control oil and gas occurrences and permit us to argue that the distribution of crude oil has been established — meaning that we are not likely to see the discovery of any new basins of truly large dimensions — which we arbitrarily put at 20 BBO.

Production by country/area

Given the uneven distribution of oil resources shown on Figures 6 and 7, one might expect a general quantitative matching of the resource distribution with the production. Figure 8, however, shows that, as of 1988, production was fairly evenly divided, with OPEC having slightly more than $1/3$, the combination US-USSR having slightly less than $1/3$, and the rest (Other-non-OPEC) with the remaining $1/3$. The Middle East, in spite of their overwhelming resource dominance, only has about $2/3$ of the OPEC share. Other-non-OPEC, of itself, is also imbalanced in that only about five countries are responsible for more than $1/2$ of that $1/3$ share of world production. China is one of those five countries and Malaysia/Brunei just miss as being a part of the top five.

Production-historical and scenario

The left side of Figure 9 shows past production. The right side shows a prediction of production in the next two decades. With respect to present production, the three groups in question, OPEC, US-USSR, and Other-non-OPEC, as was shown on the pie chart (Fig. 8), are all three producing about the same amounts. Other-non-OPEC and the US-USSR got to their positions by steady production increases over the decades; high prices did not produce any irregularities in the curve; they just permitted steady development. One of the groups, Other non-OPEC, appears youthful in its production curve and the scenario suggests production increases at least to the year 2000. The US-USSR, however, has topped out, even with the support of earlier high prices, and appears to be on decline. The general idea of this paper was prepared before the economic and political collapse in the former Soviet Union (Masters et al., 1990). The actual decline is even more rapid than shown on this graph but the principle is the same. OPEC, on the
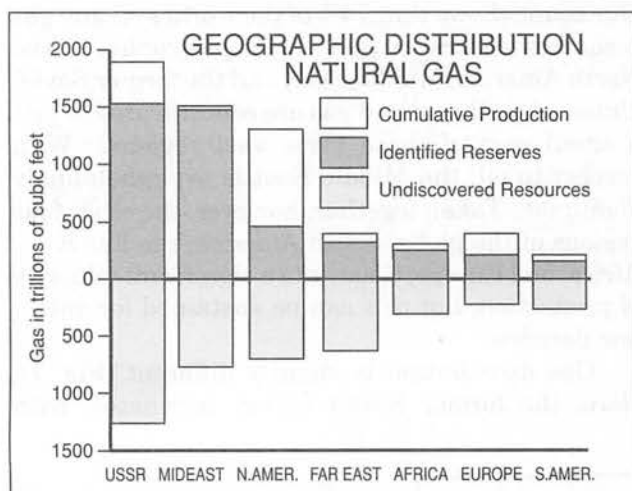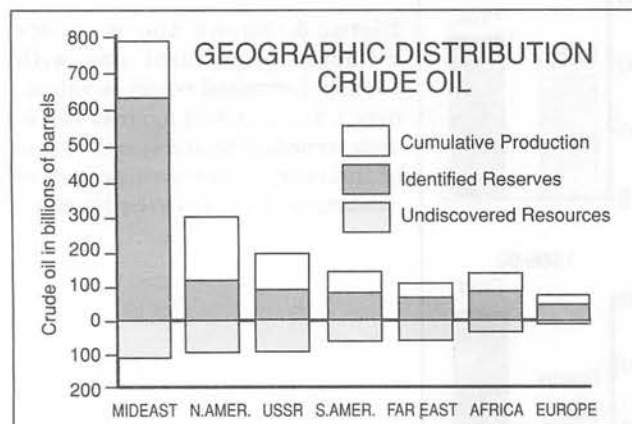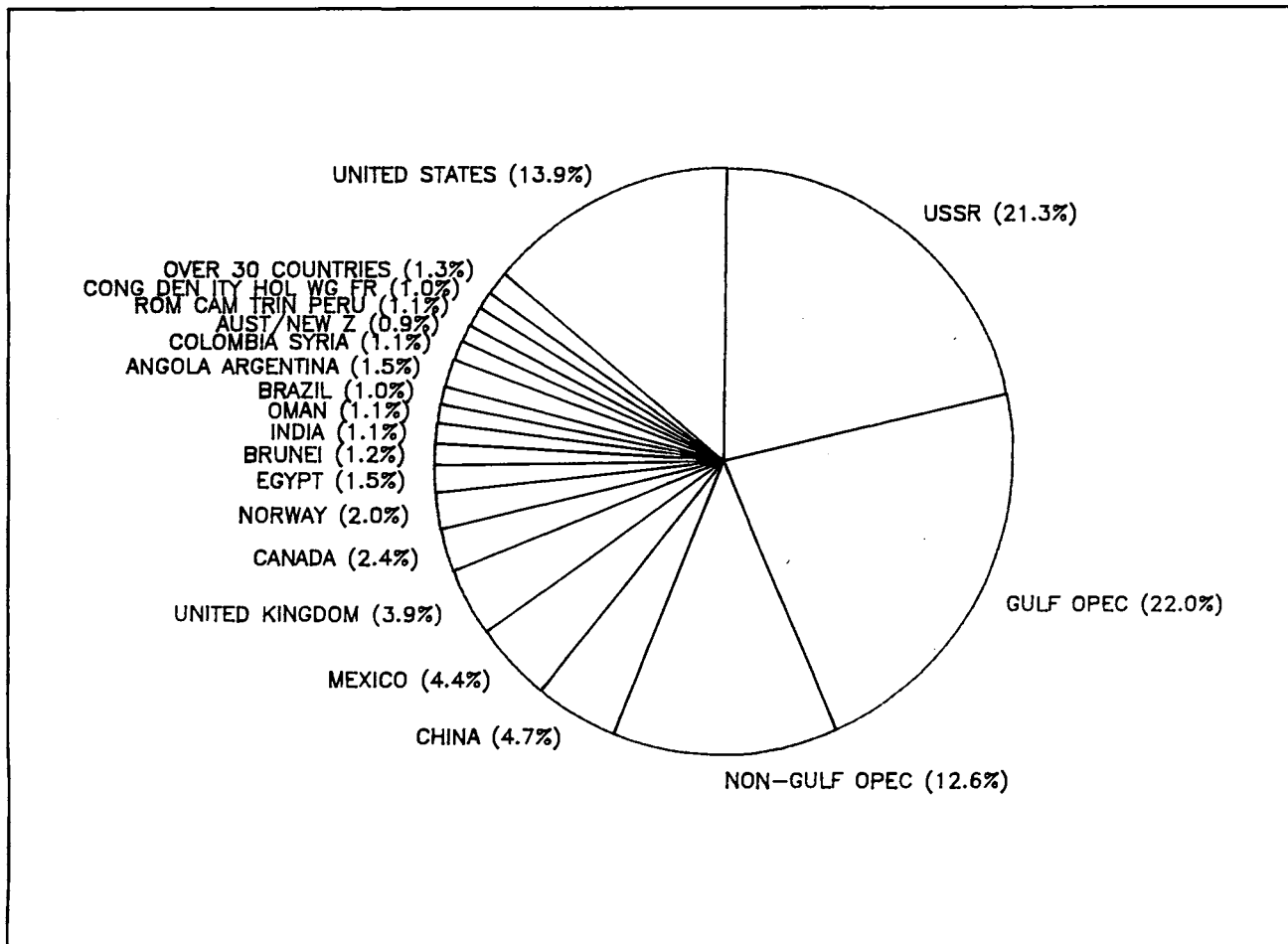
Figure 8. Shows world crude oil production in 1988 by country or by country groupings.
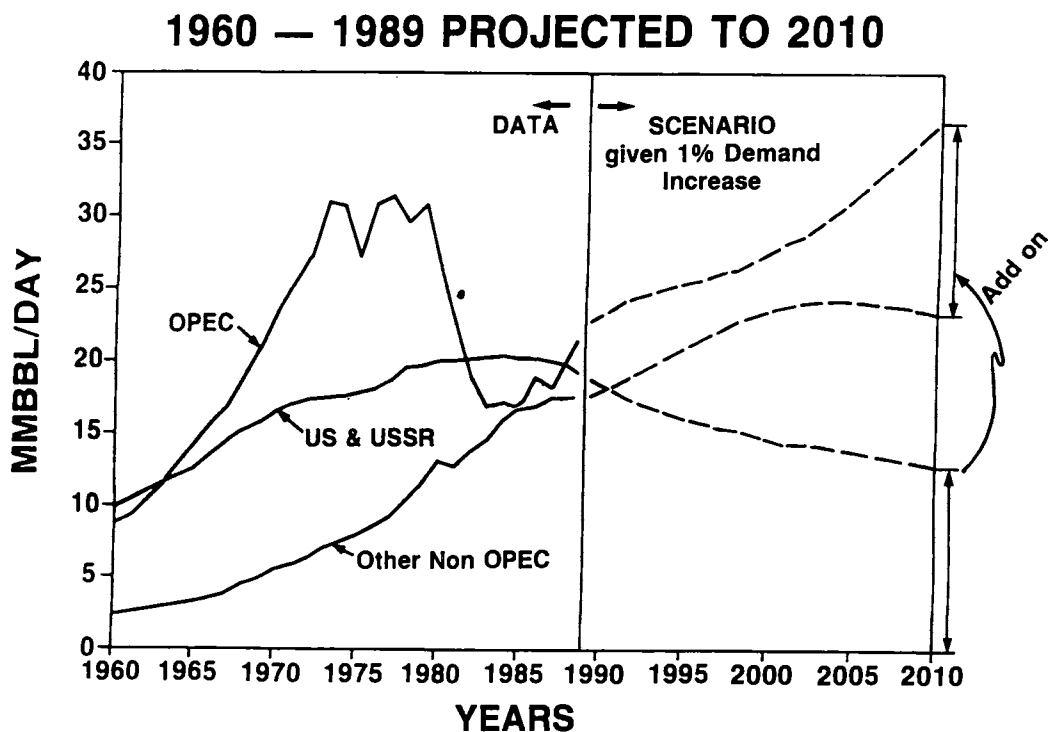
1960 — 1989 PROJECTED TO 2010

Figure 9. Shows world crude oil production, historic and scenario, by country grouping.

other hand, had to absorb a demand reduction owing to high prices in the early 80's and are now recovering with a steady increase in demand.

For scenario development, we reasoned that OPEC could develop whatever necessary additional producing capacity over and above the supply capabilities of everybody else. Given a 1% demand increase, world production will rise to some 72 million BOPD (barrels oil per day) and the OPEC share will increase, as shown, to some 36 million BOPD, which is the difference between the world demand and the supply capability of non-OPEC. For the non-OPEC scenarios, we calculated, by country, a dynamic annual reserve based on Proved Reserves, on production, and on additions to the present reserves through discovery of the estimated undiscovered resources and through field growth. For annual production levels, from that dynamic reserve, we assumed a Reserve to Production ratio of 15. The resultant production is optimistic in that it requires not yet effected discovery results, but, certainly, we can expect economic incentives to encourage discovery. It is well for us, however, to remain mindful of the enormous discovery and development task that lies ahead just to meet this scenario. The figure shows that, by 2010, production from the US and USSR will have declined in about the same amount as Other-non-OPEC has increased. Note also that Other-non-OPEC is likely to have peaked about the year 2000 and will be on the way down by 2010. When you add the two together — Other-non-OPEC plus the US-USSR — the sum is 36 million BOPD or ½ the estimated demand level for the year 2010. OPEC, then, will be producing 50% of world demand with the trend being that their share will continue to increase along with the dominant share of the Middle East.

These are scenarios with given conditions, not projections, but they do yield some perspective on the perceived resource constraints in the equation. It's one thing, however, to show some curves which lay out a resource target for OPEC; it may be quite another task for OPEC to actually increase production by 14-15 million BOPD as suggested here would have to take place. It is not an easy task and we can only trust they will find a way.

Resource Distribution by basin

The various figures and bar charts show our hypothesis of the overall quantities of oil and gas and their distribution. But what is the underlying geology that controls this distribution? Figure 10 shows basins where Crude-Oil-Futures quantities, in the sense of Identified Reserves plus Undiscovered Resources, are recognized by patterns. The patterns of the basins represent quantity differentials in six categories as recorded on the

legend. There is only one Middle East pattern representing the top of the scale, but there are many areas and patterns representing the bottom of the scale. The West Siberia Basin could well have been represented in the highest category on this diagram (and it is the only other basin in the world even close), but, at the time of this map preparation, it only measured up to just less than the 100 BBO cut. Now we consider their crude oil Futures to be slightly in excess of 100 BBO and hence worthy of the higher-quantity designation, but still not comparable to the Arabian Iranian Basin with its hundreds of billions of barrels of Futures potential.

Inspection of the map shows that a central band of the higher-quantity areas extends from the Caribbean-Gulf region, through the Mediterranean and the Middle East, and on into South Asia including southern China, Malaysia, and Indonesia. In addition, the higher-quantity patterns are more prominent in the northern hemisphere than they are in the southern area.

Realms of Petroleum Occurrences

Two of our program scientists, Gregory Ulmishek and Doug Klemme, have proposed a pattern to this distribution comprising four Realms of world petroleum occurrence (Klemme and Ulmishek, 1991) as shown on Figure 11. The squares and circles, respectively, show the location of major and moderate petroleum occurrences. The central area, which they refer to as the Tethyan Realm, and which includes most of SE Asia, is responsible for 68% of discovered world oil and gas. The Boreal Realm, to the north, accounts for 23% of discovered petroleum. The South Gondwana Realm has 4% and the Pacific Realm 5% of discovered oil and gas. The Pacific Realm, as defined here, consists of only the narrow tectonic rim of the Pacific. It does not include the entire Western Pacific Basin, as defined in this conference format, which is included, in large part, in our Tethyan Realm. With respect to this Futures map, the proportions we define for the various realms would not change significantly if calculated for Ultimate Resources — that is, were we to include the Undiscovered Resources as well. They, too, are concentrated in the Tethyan and Boreal areas.

We believe there are geologic reasons for this distribution. The occurrence of oil and gas is a function of the combination of five independent variables, source rock, reservoir rock, trap, seal, and timing (Fig. 12). All must be at least positive for oil to occur. Most must be good for large occurrences of petroleum resources. Three of these variables, source rock, reservoir rock, and seal, are strongly climate controlled and favour the equatorial
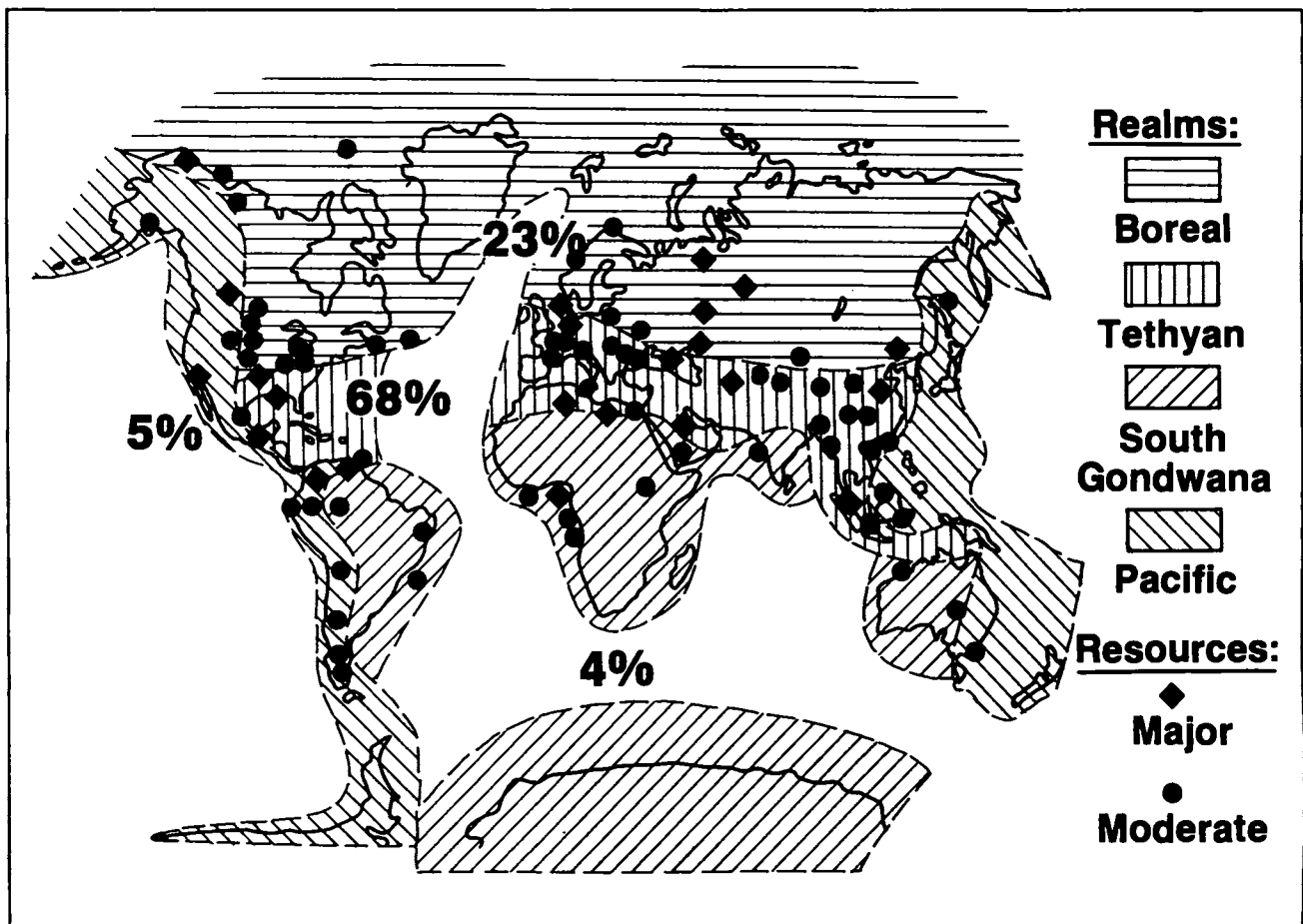
Figure 10. A map of Crude Oil Futures showing quantities of oil, expressed in six different categories of amounts and including Identified Reserves plus Undiscovered Resources.

Figure 11. Shows the four Realms of world petroleum occurrence with the locations of major and moderate-sized deposits of both oil and gas.

NECESSITIES FOR OIL OCCURRENCE:
- Source Rock
- Reservoir Rock
- Trap
- Seal
- & Timing

Figure 12. Lists the five independent variables necessary for petroleum occurrence.

region between the 30° latitudes, north and south, i.e. the Tethyan Realm, and for the following reasons: 1) The quantity of Source Rock organisms is favoured by the warm climate; and further, the absence of non-marine lake turnover in warm climates favors the maintenance of anoxic conditions. 2) Carbonate rock deposition is strongly favoured between the 30° latitudes which not only adds a reservoir that does not exist in high latitudes, but also provides a reservoir rock with properties which can be sustained for relatively deeper burial depths than can a sandstone. And 3), evaporite seals, especially salt, can only be deposited in the

low latitudes. Unrelated to climate, the Tethys of the eastern hemisphere opened and closed, plate tectonically, throughout Phanerozoic time yielding several stages of structural development and trap formation. The fact that all of these parameters remained generally favourable throughout geologic time honours the timing variable so all factors have been significantly favourable throughout most of the Tethyan Realm.

Examples of this geology will be discussed below, but first, consider the properties of the other Realms. The Boreal Realm is favoured by some parts of it having been located within the equatorial region during its Paleozoic history. As a result, the benefits of rich source rocks, carbonate reservoirs, and salt seals graced parts of North America and the former Soviet Union. The later Mesozoic period and, particularly, the Jurassic, enjoyed an abnormally warm climate which may have helped to generate the rich, oil-prone Upper Jurassic source rock of the North Sea and of West Siberia; otherwise, source rocks of the Boreal Realm tend to be carbonaceous and gas prone.

Parts of the South Gondwana Realm have experienced the favourable climatic elements of

low latitudes only since the Gondwanaland break-up of the late Jurassic. This continental migration to low latitudes worked in the favor of at least some of the pull-apart and delta basins on the east coast of South America and the west coast of Africa. Prior to the Gondwana breakup, all of the continental mass, except for northern South America and northern Africa, was held south in the high latitudes proximal to the present location of Antarctica. After breakup, the continents were free to move north to low latitudes, but, in so doing, they also retained their highstanding character, relative to sea level, and, of course, that was to the detriment of petroleum basin development.

The fourth Realm is that of the Pacific, and it is defined, not by climate, but by tectonics. As a result of subduction, most of the pre-Tertiary section has been destroyed and the Tertiary reservoirs are so laced with volcanics as to be rendered ineffective. A few regions, such as southern California, avoided the tectonic catastrophes.

Examples of Resource Occurrence by Realm

Figure 13, a cross section of the Arabian Iranian Basin, after Murris (Masters et al, 1982), demonstrates the favourable characteristics of

Tethys: 1) Good source rocks were developed at three different stratigraphic levels, Silurian, Upper Jurassic, and Middle Cretaceous. 2) The oil was contained by seals (caps) to create independent petroliferous systems, owing to the recurrent deposition of evaporites and salt — first in the Triassic, followed by Upper Jurassic, and finally Miocene. The Triassic salt seal was particularly significant in preventing the massive gas resources of the Paleozoic from flushing out the overlying oil deposits. And 3), carbonate rocks, along with sandstones, provided favourable reservoirs for each petroleum system.

Source rocks and reservoir rocks, however, are not always deposited in juxtaposition for easy charging of a reservoir. For example, the principal Paleozoic reservoir, the Permian Khuff limestone, was brought into contact with the Silurian source rock by unconformity owing to a tectonic event. Figure 14, showing the location of Middle East oil and gas fields (Masters et al, 1982), demonstrates the preponderance of gas in the southern Gulf, and the geographic association of that gas with the Qatar Arch. The unconformity relation, described above, occurs along the NE-SW trending Qatar Arch. From Ghawar field in Saudi Arabia to the
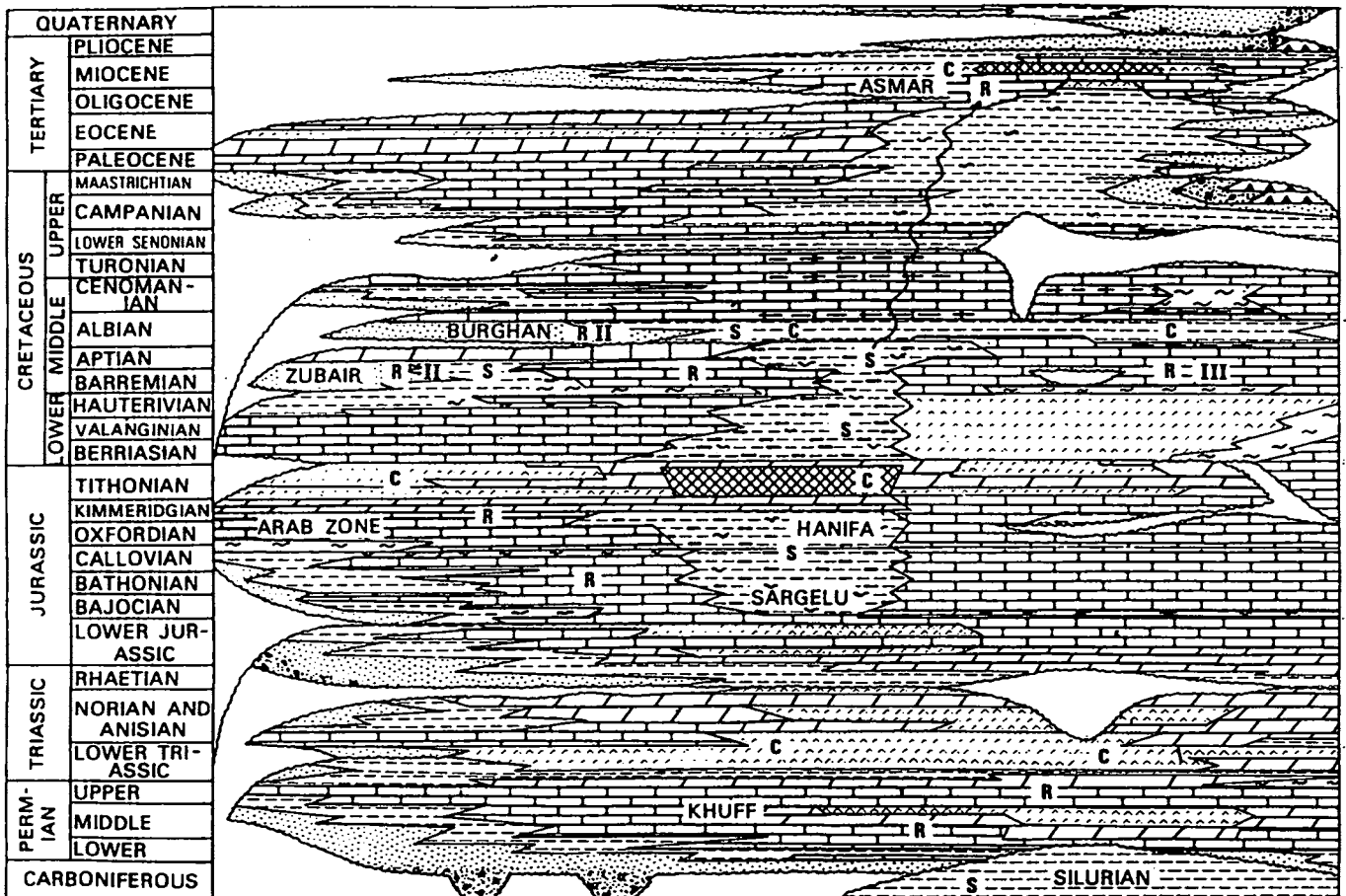

Figure 13. Middle East stratigraphy, showing source rock (S), reservoir rock (R), and cap (seal) rock (C).

east, the Silurian source rock is deeply buried and yields gas. North Dome, likely the largest gas field in the world, occurs on top of the arch to the northeast of the Qatar peninsula. The concentration of gas fields, in the southern Gulf region, is a further reflection of this geologic condition.

To the west of Ghawar, the Silurian source rock is not so deeply buried and has generated oil for the large new discoveries southwest of Ghawar in Carboniferous sandstone reservoirs, as reported by the Saudis but not recorded on this map. In the USGS assessment, we thought the area was too close to the outcrop. We were wrong. Too little is known about these discoveries to be overly predictive but, at present, we believe the same unconformity principles apply as for the gas to the east. We anticipate, therefore, that the Paleozoic oil play will be constrained by the geographic position of the Qatar Arch and its extension, and probably not extend north toward Iraq. But, clearly, the explorationist should be on the lookout for early structure.

Another example of superior conditions for oil occurrence, in the Tethyan Realm, is found in the East Venezuela Basin (Fig. 15). Venezuela has massive oil deposits in Maracaibo but our focus is on East Venezuela and recent discoveries that serve to emphasize the richness of the region. Already, East Venezuela is one of the great oil basins in the world with the Orinoco extra heavy oil belt, bordering the Guyana shield to the south, composing the largest single occurrence of oil in the world — more than 1 trillion BO (barrel of oil) in place, albeit unconventional and extra-heavy. Light oil is recovered from fields, basinward, to the north. The famous La Luna source rock of Middle Cretaceous age is the source of most of the oil and is the high-quality element which makes Venezuela one of the richest locales for oil in the world. The strip-back cross sections (Fig. 16) suggest the common origin of these deposits with Orinoco extra-heavy, starting to migrate as an immature oil probably as early as Eocene, but before the development of major reservoirs. By Oligocene time, the principal reservoir section developed to receive the immature heavy oils. But with continued basinal subsidence to the north, the basement crust to the south yielded to faulting, as shown on the lower section, which, by disrupting the migration path, captured the flow of now more mature, lighter crude oil in the Officina and related fields.

Recently, Venezuelan explorers have encountered a still later phase of the migration into traps directly above the La Luna source rock kitchen. These discoveries are associated with thrust fault traps on the north flank of the basin. The El Furrial discovery and trend is the newly-
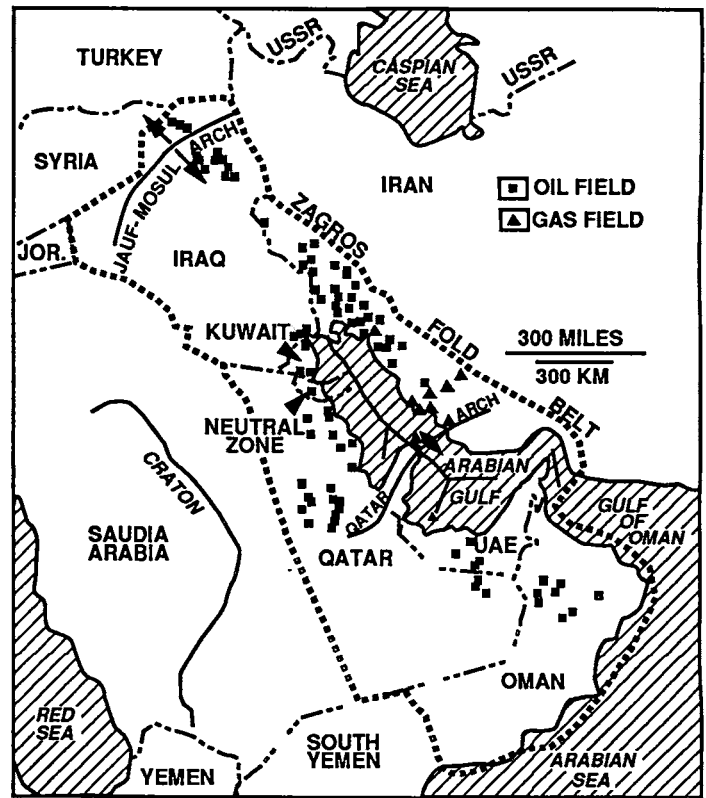

Figure 14. Middle East oil and gas fields. Gas fields are concentrated on the Qatar Arch and its extension to the N.E.

found occurrence of La Luna oil (Fig. 17). Its discovery had to await the ability of seismic to see complex structure at great depth and the Venezuelan explorers have been well rewarded with what had to be an unexpected 700 m of high-quality sandstone reservoir rock. As the other wells and dates on the cross section indicate, discovery was not simple, but, rather, involved exploratory efforts over many years.

Several successful wells have been drilled along the NE-SW structural trend of the Furrial Play (Fig. 18), but the full story has not yet evolved. It is our understanding that an expected east-west oriented depositional strike could result in a limiting facies-change loss of reservoir to the NE. To the SW, increased depth of burial is likely to turn the play into gas. However, the development details evolve, this is one of the great play successes of our time and we can enjoy its geographic and geologic evolution.

And there is more to La Luna relative to the continent. The favourable source rock conditions extend both to the east and to the SW. To the east, in the Guyanas, there is no structure, but to the SW is a foreland fold belt in both Colombia and Ecuador. We considered the resource potential in Colombia as quite favourable but thought La Luna would be so deeply buried as to produce gas. But
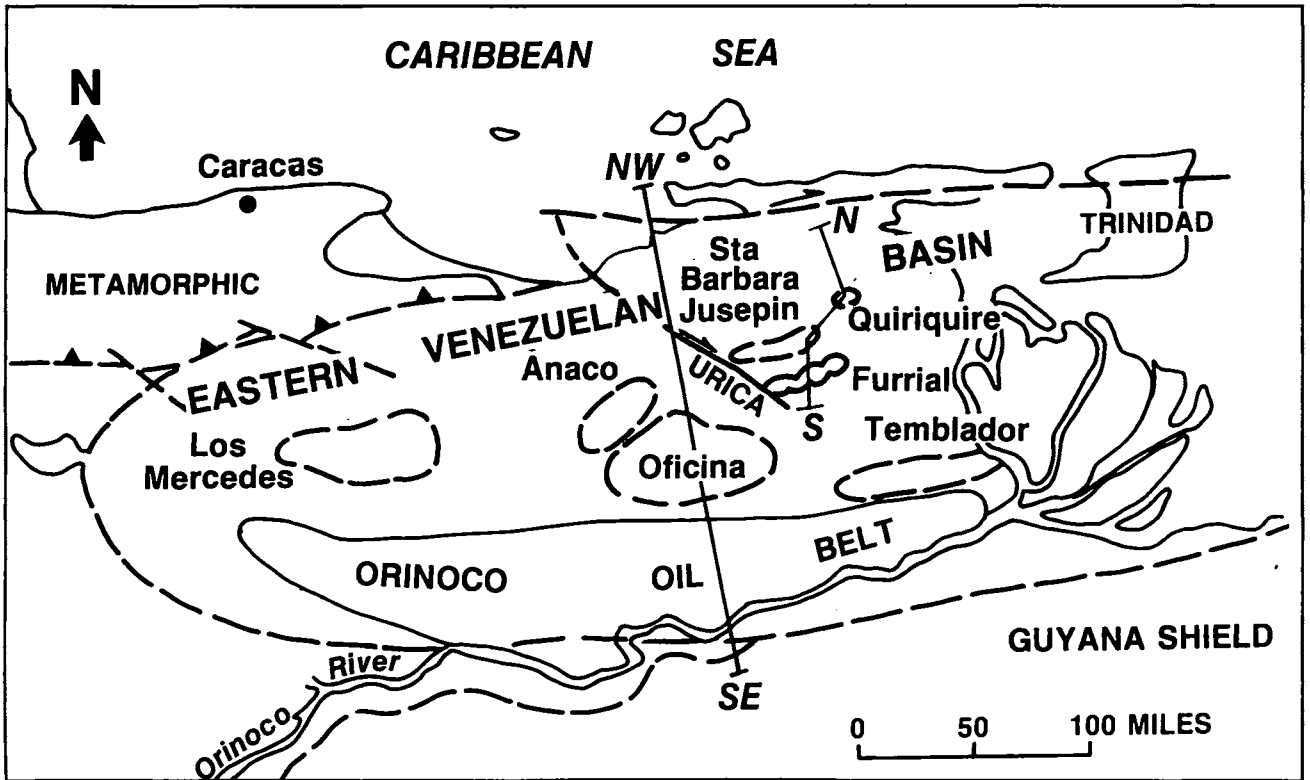
Figure 15. Map of Eastern Venezuela Basin showing location of cross sections and major occurrences of petroleum.
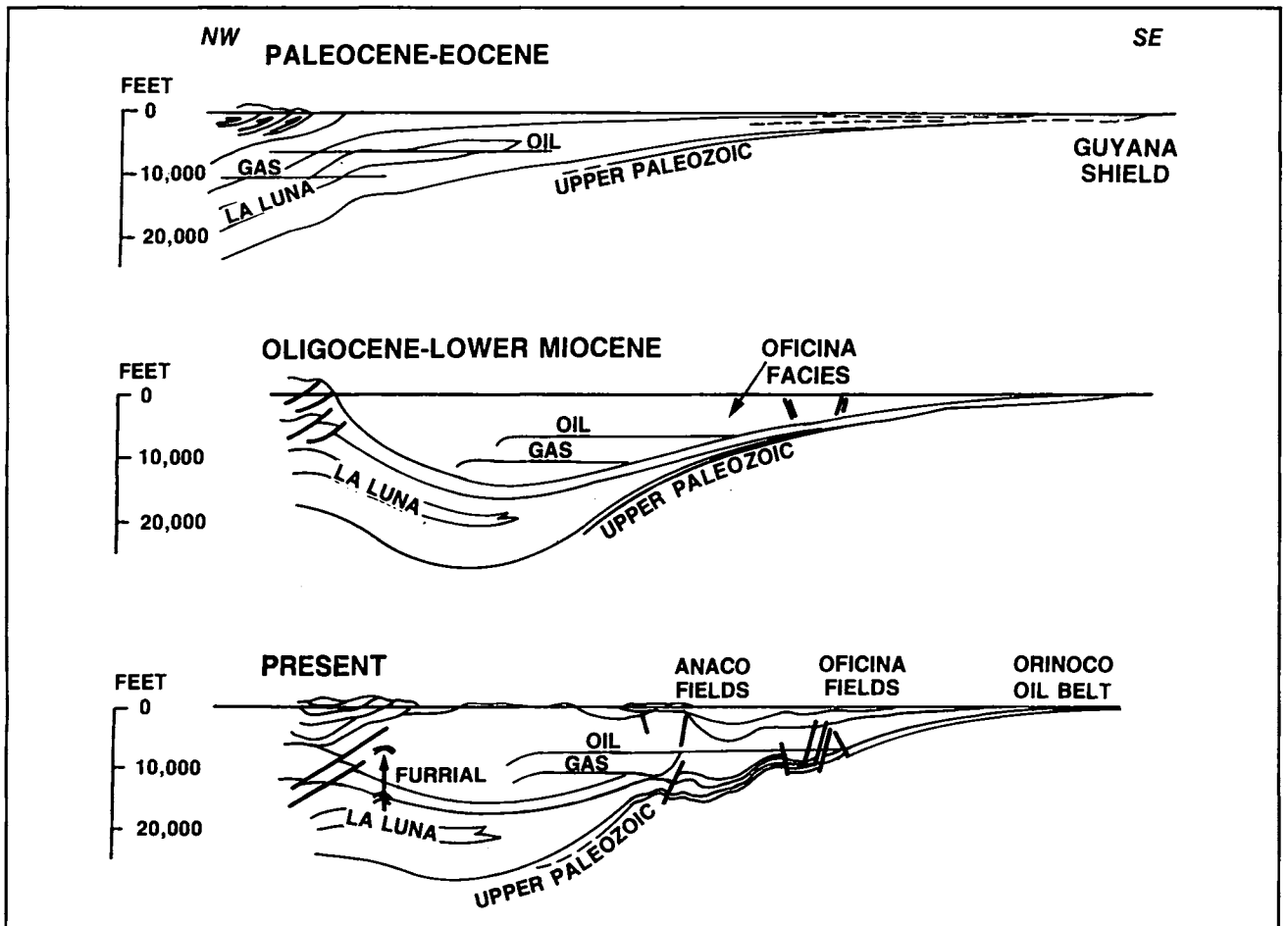

Figure 16. NW-SE strip-back cross section (see Fig. 15 for location) showing sequence of geologic events leading to the petroleum occurrences.
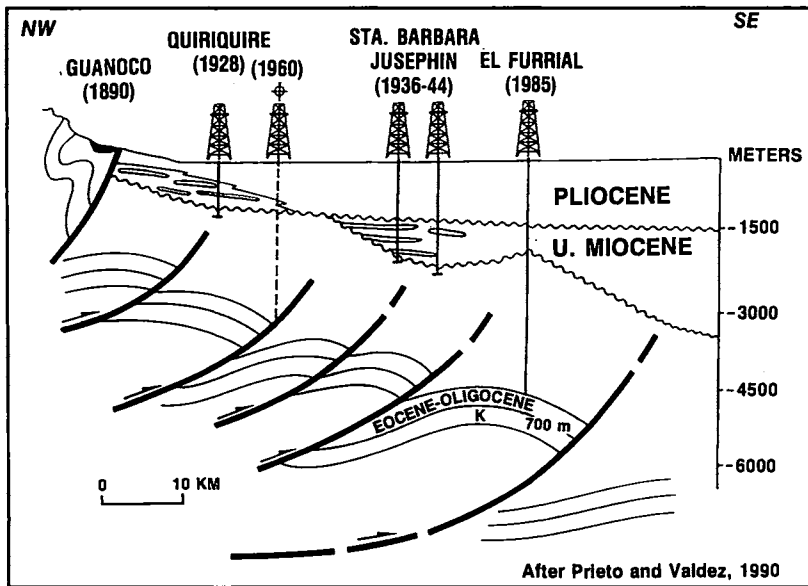
Figure 17. N-S cross section (see Fig. 15 for location) showing structural setting and historical development of oil fields on the northern overthrust flank of the Eastern Venezuela Basin.
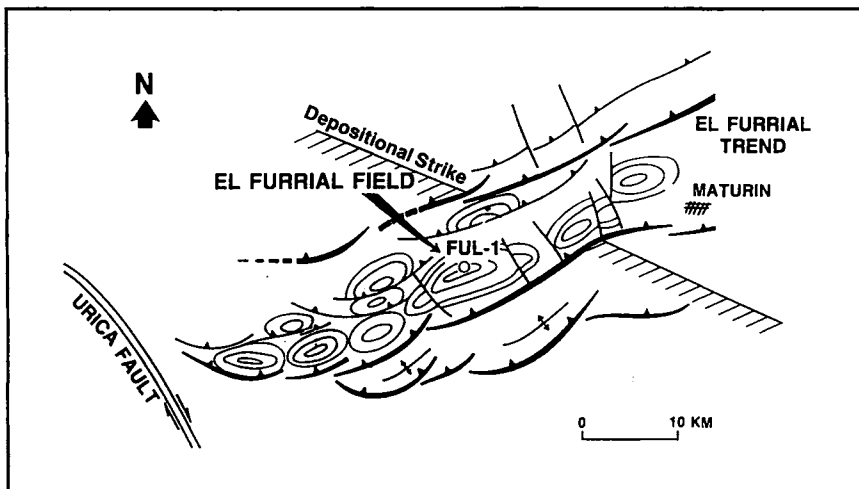

Figure 18. Structure map of Furrial field, and vicinity, showing crossing depositional strike.

not so; the recent BP discovery, Cusiana, may be very large, up to 2 BB (billion barrels), recoverable, of very light oil but the structure is a complex mountain front situation and delineation drilling and seismic is just now taking place.

Figure 19 is a cross section from the North Caspian Basin of Kazakhstan that extends through the Tengiz field. The area is located south of the Volga Urals Province of Russia. We assign the area to the Boreal Realm. In Paleozoic time, this area was located in a more equatorial climate region and hence permitted the development of rich source rock, which here is essentially facies equivalent to good carbonate reef reservoir development. A salt seal developed over the top to hold in the very large occurrences of crude oil. These favourable conditions for oil also make development expensive in that thick salt is difficult to drill through and associated sulfur creates a highly acidic environment, as well

as high-volume, free-sulfur by-products which require disposal.

Eastern South America and West Africa are part of the South Gondwana Realm. Their oil favorability stems almost entirely from the low latitude positions they have assumed since the post Jurassic Gondwana breakup. In particular, we believe the passive margin rift play, with dominant lacustrine source rocks, in order to have good potential, needs a warm climate without annual winter-lake turnover which would otherwise oxidize the bottom sediments. We interpret these conditions to have occurred in the development of the rocks shown on the cross section from the Campos Basin of Brazil (Fig. 20) which can also serve as an analogue for the West Africa basins. The sediments in the rift, above basement, are syn-rift fluvio-lacustrine and contribute the main source rock. The overlying transitional marine/non-marine
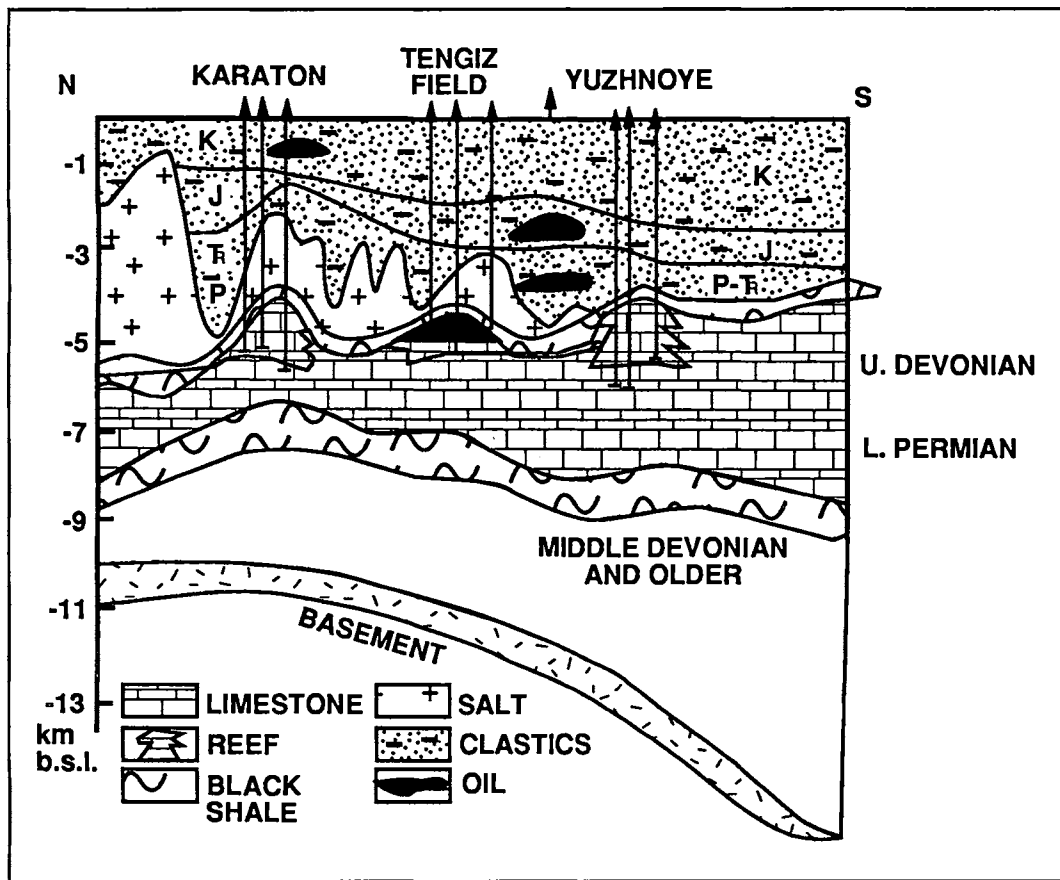
Figure 19. Cross section of North Caspian Basin, Kazakhstan, showing tectonic and stratigraphic setting of the Tengiz oil field.
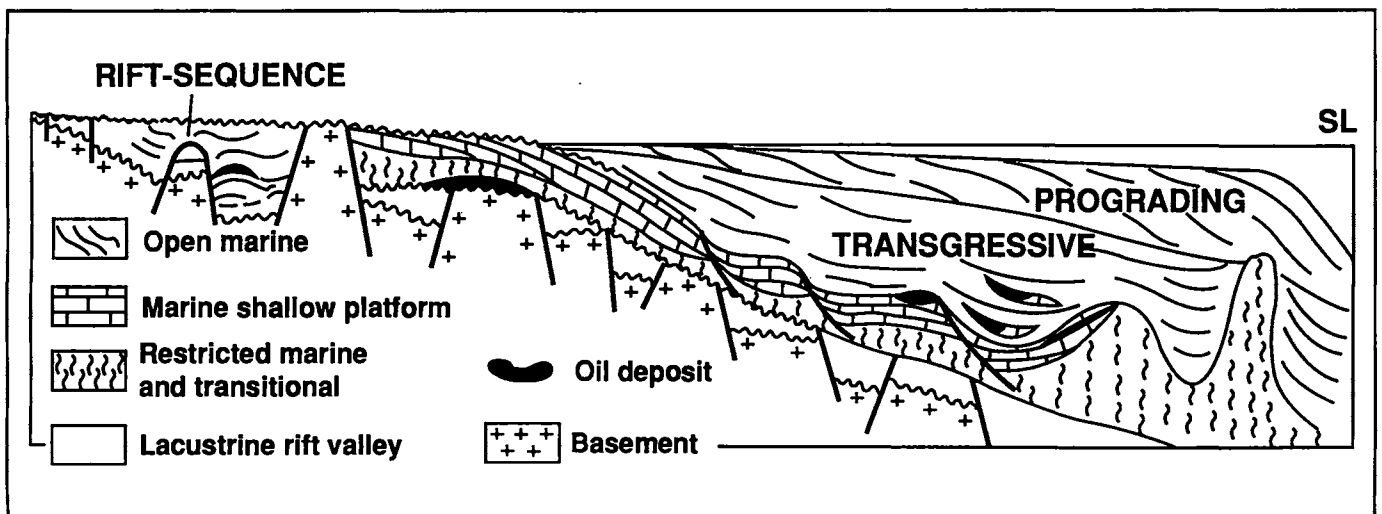

Figure 20. Cross section of Campos Basin, Brazil, showing stages of basin development and locations of oil deposits characteristic of basins on Rifted Passive Margins.
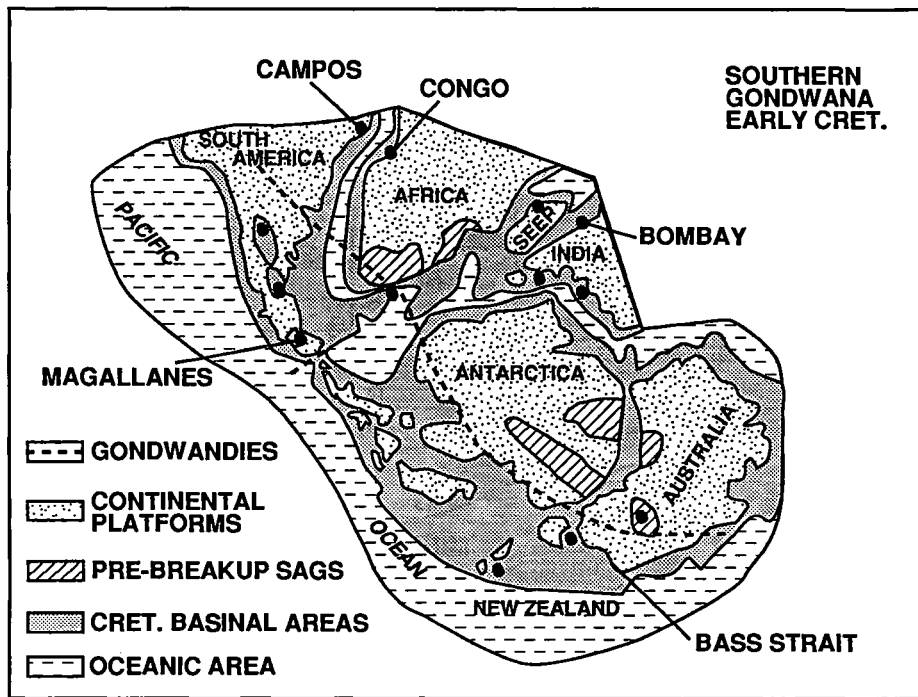
Figure 21. Map of southern Gondwana showing plate tectonic positions of Continents in Early Cretaceous time.

sediments, including salts, serve to seal temporarily the source-kitchen until later fracturing permits upward migration to carbonate rock reservoirs, or to turbidite reservoirs in the transgressive sequence. The turbidites comprise supergiant fields in this setting, and have become a major play and target in similar environments throughout the world, but nowhere has the play been as successful as in the Campos basin.

We find this a particularly difficult play to assess because of the uncertainty and variability of turbidite occurrence. At a low probability, certainly, the resource quantity must be large, but we remain cautious in our assessments of the most likely occurrence.

Further, we must be cautious about assuming that all passive margins are alike. The geologic development of the basin type is such that only one source rock commonly develops and, if that is buried too shallow or too deep, as it is along much of the coast of Brazil, or too deep, as it is along the east coast of the US, then the oil source rock is either not mature or is overmature and no oil occurs.

On the west coast of Africa, basins developed in South Angola and Namibia but the required lacustrine rocks did not occur or were eroded.

On the east coast of Africa, where one also would presume there to be Passive Margin Basins, there is instead an area of anomalous tectonic development and the required ingredients for petroleum occurrence have not evolved.

Figure 21, a map of Early Cretaceous time, shows Gondwanaland at a preliminary stage of breakup. It can be seen that similar passive margin plays must be reckoned with in association with the Australian and East Antarctica breakup as well as with the former connections with Africa and India. These passive margins, however, developed at relatively high latitudes and presumably suffered oxidizing winter-lake turnovers. We do not, therefore, anticipate good source rock conditions and, accordingly, down-play the potential resources for the area. It is not as easy, however, to dismiss the potential for good Jurassic source rocks in the Weddell Sea considering their having been sampled just to the east of the Falkland Islands. We do not, however, assign good reservoir rock to the Weddell Sea area, so overall our assessed potential is low.

CONCLUSION

We now consider, for the world, that most of the cards are on the table. We have a pretty good idea of world ultimate petroleum resource occurrence. We think we know how it is distributed, and we have a supporting hypothesis to explain our biases. The data sources are varied and reasonably consistent, in that, for most areas, we can approach the resource analysis from both geological and statistical perspectives with similar results. Such a situation does not ensure absolute truth, but it is comforting and places us in a situation of being

able to learn from the analysis of almost any new sources of data. Given the distribution of world petroleum, and the momentum generated in its consumption, we can infer the development of patterns of future supply and would suggest strongly that within less than 20 years most of the world's oil supply will come from OPEC and, in particular, the Middle East. A marked increase in the consumption of natural gas, which could be triggered in the US by environmental regulation, could make a difference in the distribution and type of petroleum energy supply, but it will require an enormous and highly risky investment in gas transportation and in conversion of natural gas into liquid fuels.

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