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India: Domestic Oil Prospects Diminish

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A Research Paper

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NESA 86-10039
October 1986

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India: Domestic Oil Prospects Diminish

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A Research Paper

This paper was prepared by Office of Near Eastern and South Asian Analysis. It was coordinated with the Directorate of Operations.

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India: Domestic Oil Prospects Diminish

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Key Judgments

Information available as of 1 August 1986 was used in this report.

A detailed analysis by a contractor of India's natural resource base and the operation of its domestic oil industry suggests that oil production will decline significantly from 600,000 barrels per day (b/d) in fiscal year (FY) 1985 to 490,000 b/d in FY 1989 and 275,000 b/d by the end of FY 1994. Rapidly rising domestic energy consumption, declining supplies of noncommercial energy, and intractable problems in the coal and electrical power sectors will force India to greatly increase oil imports or face slower economic growth. Domestic oil production will cover only 40 percent of demand in FY 1989, compared to about 65 percent in FY 1985.

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Indian Government planners, while forecasting a growth in production to 690,000 b/d in FY 1989, have nonetheless demonstrated concern over the prospects for increased oil production. A lack of new oil discoveries since the mid-1970s has prompted the government to lower its estimate of proved oil reserves and to dramatically reduce its early 1980s projection of growth in oil production. The government also has launched a major campaign to enlist foreign oil companies in exploring newly opened offshore areas.

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India's need to find more oil reserves and get maximum recovery from producing fields will present the United States and other Western countries with a market for high-technology goods and services. The degree and terms of private foreign participation in the oil sector are hotly debated political issues in India, however, and government vacillation toward such participation is hindering the establishment of a business environment that would encourage more foreign investment.

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The adverse impact of falling oil production on India's foreign payments also will make it more difficult for New Delhi to increase purchases of Western high-technology and capital goods needed to modernize the economy and promote growth. India probably will seek more concessional Western aid to finance development of its oil sector as well as its economic modernization program to avoid a heavier hard currency debt burden.

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The relative importance of the Soviet Union to Indian oil exploration and development is likely to diminish. New Delhi will increasingly seek Western technology and expertise both to explore in deeper water off shore and complicated geological formations on shore and to maintain output

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from older fields. The Soviets can provide India with only second-rate equipment and technicians. Moscow also will need more of its resources at home to cope with its own production problems. 25X1

Deteriorating prospects for increased crude oil production are likely to have an adverse impact on India's foreign trade balance. Demand for petroleum could grow by more than 7 percent annually over the next several years if Prime Minister Rajiv Gandhi continues his push for greater economic liberalization and faster economic growth. The volume of petroleum imports is almost certain to increase faster than the 8-percent average annual growth projected by the government. 25X1

Increased oil imports will offset savings resulting from the fall in world oil prices over the last year. If India's crude oil demand reaches 1.2 million b/d by FY 1989, the oil import bill using a sustained world oil price of $10 to $15 per barrel would be $2.6-3.9 billion. India's oil import bill in FY 1985—with crude oil prices at slightly less than $30 per barrel—was about $3.1 billion. 25X1

The most important constraint to increasing domestic oil production in India is its resource base. According to a study conducted by the United States Geological Survey, India's undiscovered recoverable onshore oil reserves are probably spread over so extended an area that no new major commercial reserves may be found. Analysis of the USGS report also indicates India may have no economically viable offshore reserves beyond those already discovered. 25X1

The most likely scenario developed by the contractor suggests that onshore production will decline rapidly from the FY 1985 level of 200,000 b/d to 100,000 b/d by FY 1994. Discoveries in new areas probably will contribute no more than 25,000 b/d in FY 1987 and decline to about 14,000 b/d by FY 1994. Even this may be optimistic, since it assumes that discoveries in virgin territories will be brought on stream continuously and without delay. 25X1

Technical analysis shows that offshore production will probably decline from the FY 1985 level of 400,000 b/d to 350,000 b/d in FY 1987, stabilize through the end of FY 1989, and decline to 175,000 b/d by the end of FY 1994. The forecast of offshore production is based primarily on output from the Bombay High field with a minor amount from small fields

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in the area. Outside the Bombay High area, the leadtimes involved in developing new areas off shore almost guarantee that none will be developed through FY 1989, and the outlook beyond that is not bright.

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Prospects for increased natural gas production are more favorable, but, without major new investment, gas production will be barely sufficient to supply fertilizer plants already planned over the next few years. Further development of known reserves and additional gas discoveries are not likely to be a factor in this decade.

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Problems within the domestic oil industry will be a major drag on India's efforts to increase current production from known reserves and to exploit new fields. Indigenous drilling capabilities and management techniques are poor by Western standards. The Indians do not have the technology or expertise required for sophisticated exploration and development in the severe operating environments and/or the complicated geology where new Indian discoveries are likely to be found.

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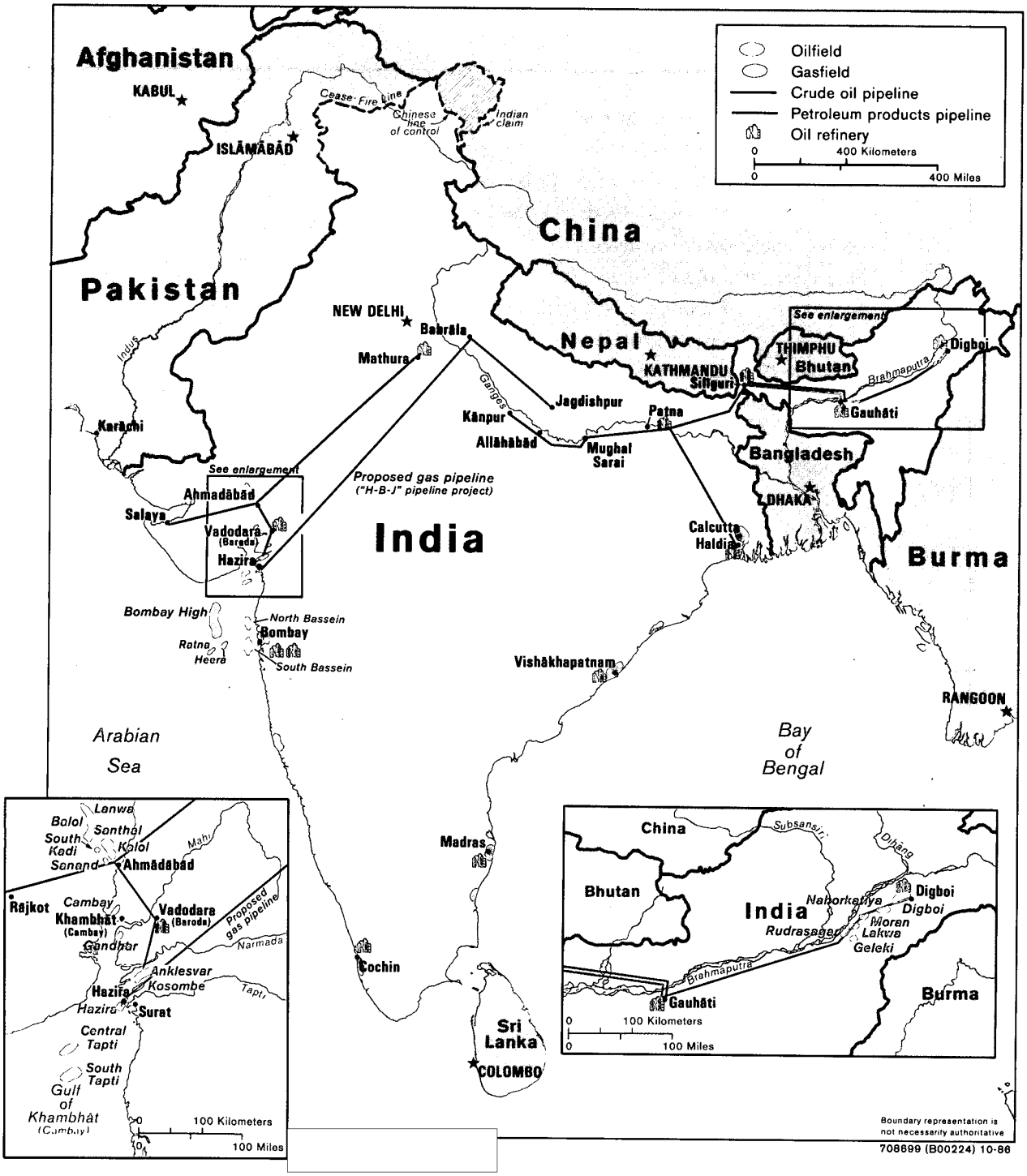
Figure 1
The Indian Oil and Gas Industry



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India: Domestic Oil Prospects Diminish

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In the late 1970s, prospects for India's future oil and gas production brightened with the development of the offshore Bombay High field—India's largest oilfield—and increased government support for offshore exploration by foreign companies.[1] Some Indian officials publicly speculated that the country had a chance of achieving oil self-sufficiency.

Increasing domestic oil production in the early 1980s helped India maintain economic growth while lowering its trade deficit. Domestic production provided about 65 percent of India's oil consumption last year.[2] The Indians still are forecasting some growth—or at least maintenance—of current oil production levels through the remainder of this decade. In contrast, a CIA contract study projects a sharp decline in Indian oil output through 1995.

Current Oil and Gas Production

India's crude oil output has increased by an average of 13 percent annually since the beginning of commercial oil production from the Bombay High oilfield in 1976 to about 600,000 barrels per day (b/d) in fiscal year (FY) 1985.[3] The Bombay High field accounts for about two-thirds of national production. Most remaining production comes from onshore fields in Assam and Gujarat.

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India also produced about 790 million cubic feet per day (cf/d) of natural gas in FY 1985, the equivalent of about 135,000 b/d of oil. Associated gas from the Bombay High area accounted for slightly over half of domestic gas production. Most of the remaining gas came from fields in Assam and Gujarat.

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Contrasting Production Outlooks

Indian Government Projections

The official projection presented in the Indian Government's seventh economic development plan published in 1985[4] calls for production of 690,000 b/d in FY 1989, an increase of about 100,000 b/d over the FY 1985 rate, but a review of public statements by Indian officials suggests that many are dubious about reaching this level of oil production. The US Embassy reports that Indian estimates of production in FY 1989 now range from 600,000 b/d to 700,000 b/d—roughly the official estimate of future production. The Minister of State for Petroleum presented before Parliament last November production estimates of 610,000 b/d for FY 1986, 630,000 b/d for FY 1987, and 640,000 b/d for FY 1988. There is no longer Indian talk of self-sufficiency.

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India estimates that natural gas production will increase to about 1.5 billion cf/d in FY 1989, according to the government's development plan. Offshore

[2] Indian planners are projecting crude imports of about 300,000 b/d in 1986, almost all from Saudi Arabia, Iran, Iraq, Kuwait, and the United Arab Emirates. About one-fourth of these crude imports will be delivered on Soviet account under the Indian-Soviet trade agreement and will not require hard currency payment. New Delhi will also import an estimated 90,000 b/d of petroleum products.

[3] The Indian fiscal year begins on 1 April of the stated year.

[4] The seventh five-year plan ends in FY 1989.

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production from a natural gasfield currently being developed is projected to become a major factor in the energy scene in FY 1987 and by FY 1989 will account for about half of India's natural gas production. Offshore associated gas—natural gas produced along with crude oil—from the Bombay High field is projected by India to peak in FY 1987 and then begin a fairly rapid decline to 390 million cf/d in FY 1989. Total onshore associated gas production will remain fairly constant at about 300 million cf/d.

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Alternative Production Outlook

A CIA contractor concludes that Indian crude oil production will decline to 490,000 b/d in FY 1989 and 275,000 b/d in FY 1994. This estimate is based primarily on estimates of India's reserve base and the limitations of the domestic oil industry that are more pessimistic than those of the Indian Government. A detailed look at the distribution of oil-bearing geological formations in India suggests that the country's undiscovered recoverable oil reserves of 1.4 billion barrels are contained in so extended an area that no major new commercially viable reserves may be found. Even if commercial reserves are found, they probably will require sophisticated and expensive Western expertise and equipment for exploitation and are not likely to result in significant production increases in this decade. Prospects for natural gas are more favorable, in the contractor's judgment, and production should exceed 1 billion cf/d by FY 1989.

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Proved and Probable Reserves

The Indian Government uses an unrealistically high estimate of the country's oil reserves based on outdated and unsophisticated Soviet surveys, according to the contractor. In its current plan, the government estimates total geological reserves of oil and gas at 124 billion barrels but does not indicate what percent is recoverable. Two different joint Soviet-Indian teams estimated total recoverable oil and gas at between 41 billion and 46 billion barrels:

- In 1965 a team estimated India's ultimately recoverable oil and gas reserves, including reserves already produced, at 29.2 billion barrels of petroleum liquids (oil) and 12.2 billion barrels of oil equivalent (boe) natural gas.

Figure 2
India: Oil Production, FY 1955-85

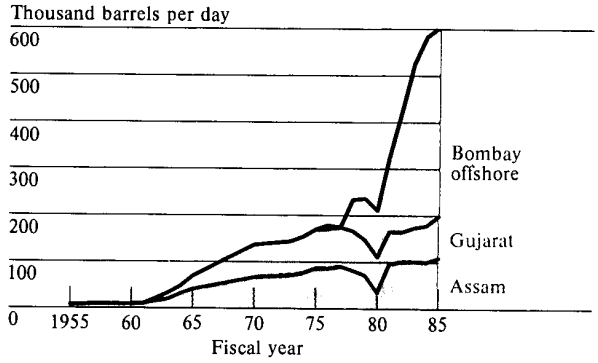

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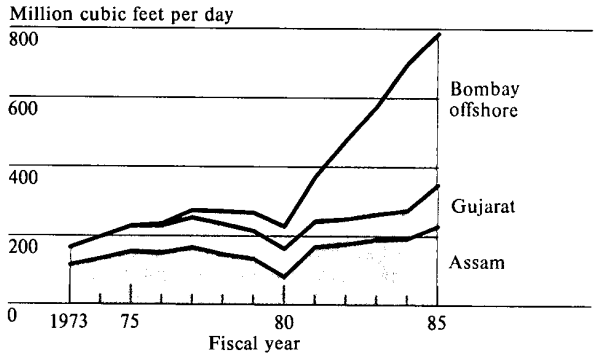
Figure 3
India: Natural Gas Production, FY 1973-85



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- In 1975 another team estimated ultimately recoverable reserves at 11 billion barrels of oil and 35 billion boe of natural gas.

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Government's Downward Revision of Oil Projections

Over the last three years, the Indian Government has steadily lowered its official projections of oil production. In late 1982–early 1983, the Oil and Natural Gas Commission (ONGC), the state company responsible for most domestic oil and gas exploration, presented two scenarios for future oil production—one called for 900,000 b/d and the other for 1.2 million b/d in 1990. Indian planners believed that 1.2 million b/d or self-sufficiency could be reached if the government was willing to finance the necessary level of exploration and development. The lower level of 900,000 b/d was not seriously questioned at that time but merely accepted as attainable.

By mid-1985, however, the government had become more pessimistic and revised its official estimate of production for FY 1989 to 690,000 b/d. We believe Indian planners lowered their estimate in large part because no major new oil discoveries have been made in over a decade. The US Embassy in New Delhi reported that the government's earlier estimate of 900,000 b/d assumed 200,000 b/d would come from fields that had not been discovered. We believe the government's more recent lower estimate also took into account lagging foreign interest in offshore areas, the domestic oil industry's poor drilling record, and the high cost of increasing output from older maturing fields.

Government Plans for Oil Production

The government projection of 690,000 b/d in FY 1989 calls for onshore deposits to provide most of the increase in production, primarily the Cambay Basin, Upper Assam, and Nagaland. Nearly half the increased production is to come from the Cambay Basin, where oil production is projected by the government to increase from 78,000 b/d in FY 1984 to 120,000 b/d in FY 1989. The government expects to achieve the increase primarily through final development of the Kalol field and development of heavy oilfields north of Gujarat.[a] The other half of the overall increase in production is projected to come from fields in Upper Assam and Nagaland, where production is expected to double from the FY 1984 level to about 90,000 b/d in FY 1989. In other aging producing areas, the government is hoping to maintain current levels of production through additional development drilling and improved well maintenance. 25X1

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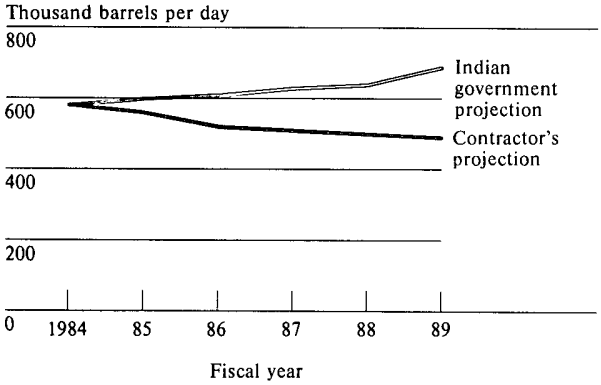
The government plan called for only a small increase in offshore production. The main effort would be devoted to drilling additional development wells and expanding the water injection program to prevent a decline in Bombay High field production. Lower oil prices, however, have sparked a debate between the government and the state oil company. The central government is now considering a slowdown in work on part of the Bombay High field. The plan also calls for about 20,000 b/d of additional production from Heera, a small field in the Bombay High area. 25X1

[a] *Some additional production may come from Gandhar in the Cambay Basin. Oil was discovered in 1983, and early this year the government claimed the field as India's second-largest geological reserve of oil after the Bombay High field. Exploration, however, is still under way, and the US Embassy does not believe sufficient drilling and evaluation have taken place to confirm the size of the reserves or the production potential. If commercial production is developed, it may only make up for declining output in other maturing fields in Gujarat.* 25X1 25X1

The contractor study indicates that the estimates of ultimately recoverable oil and gas reserves derived by the joint Soviet-Indian teams are two to five times too high. In 1984 the United States Geological Survey (USGS) estimated the most likely level of undiscovered potential oil and gas reserves at 1.4 billion barrels of oil and 2.85 billion boe of natural gas.[5] To adjust the USGS estimates to the Soviet-Indian estimates, 4.8 billion barrels of already discovered and partly produced oil must be added to the 1.4 billion barrels undiscovered, yielding ultimately recoverable oil reserves of 6.2 billion barrels. Adding in natural

[5] The USGS placed no limit on the time allowed for exploitation and did not assess the economics of prospective finds when making its estimates of ultimately recoverable oil. Potential reserves in the vast area outside the Bombay High will be expensive and time consuming to find, in the contractor's judgment. Some of the estimated undiscovered reserves will not be produced for decades—some perhaps never because, while they are technically recoverable, it may never be economical to do so. The relative sparseness of estimated reserves relative to geographic area outside current producing areas substantially increases the risk of not finding commercially exploitable reserves in any given basin. 25X1

Figure 4
Projections of Indian Oil Production, FY 1984-89



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India's Undiscovered Recoverable Oil and Gas Reserves [a]

	Undiscovered Reserves at Three Different Levels of Probability		
	95 Percent	Most Likely	5 Percent
Oil reserves *(billion barrels)*	0.73	1.41	7.14
Gas reserves *(billion cubic feet)*	8,870	16,530	61,660

[a] Total undiscovered reserves are derived from a simulation process involving all the basins and do not equal the sum of the estimates for the individual basins.

Source: US Geological Survey.

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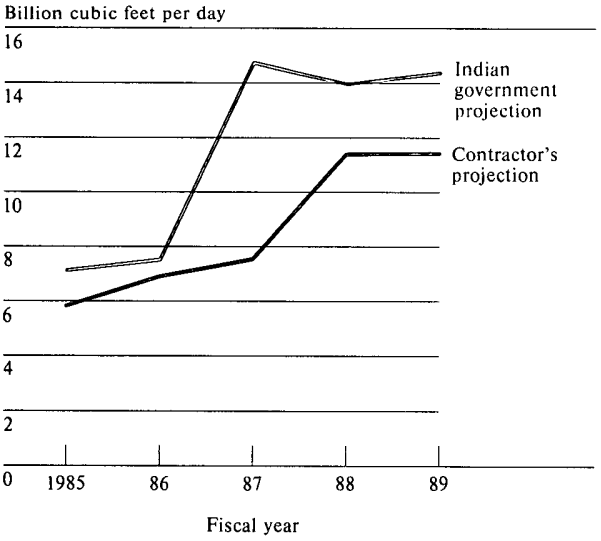
Figure 5
India: Projected Gas Production, FY 1985-89



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gas, the figure reaches 9 billion barrels of oil and oil equivalent, which is only about 20 percent of the 1975 Soviet-Indian estimate of 46 billion barrels of oil and gas. Even the USGS's most optimistic estimate—with only a 5-percent probability of occurrence—is only 22.6 billion barrels, or about half the 1975 estimate.

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The contractor's independent evaluation is even more pessimistic than the USGS report. The contractor considered the USGS estimate of 3.3 billion barrels of discovered oil in the Bombay High area about 10 percent too high. The Indians claimed that proved and probable reserves in the Bombay High were 2.5 billion barrels in FY 1983. As a result, the contractor believes discovered reserves (which include reserves already produced) should be at least 300 million barrels lower than the USGS estimate because 540 million barrels had been produced by India from Bombay High through the end of 1984. Because of the methodology employed by the USGS, an overestimate of identified or discovered reserves will lead to an overestimate of undiscovered reserves by a similar

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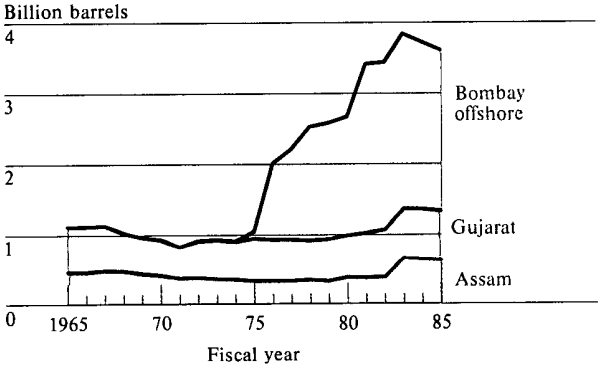
proportion—an important distinction, since the Bombay High accounts for a large share of production in the USGS estimates. 25X1

Although the Indian Government continues to use the optimistic oil reserve base derived from estimates made in the 1960s and 1970s, its official estimate of proved and indicated balance reserves reflects some pessimism in the Ministry of Petroleum (see appendix A). For the first time since the early 1970s, the government is beginning to lower its estimates of proved and indicated balance reserves. The government's estimates peaked in FY 1983 at 3.8 billion barrels and are now at 3.6 billion barrels. We believe this indicates a more realistic attitude among government officials in response to the lack of new discoveries over the last 10 years. 25X1

Figure 6
India: Ministry of Petroleum Estimate of Proved and Probable Crude Oil Reserves, FY 1965-85



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Capability of Domestic Oil Industry

India's strategy for increasing oil production over the next few years is based on the assumption that most of the remaining reserves are in small deposits, will require deep drilling, and will be expensive and time consuming to exploit. The current five-year plan calls for intensified exploration in known oil-producing areas and extending the search to inadequately explored and unexplored areas. The government intends to drill 2.8 million meters of exploratory wells during the current five-year plan period, nearly triple the drilling in the previous plan period. To carry out this ambitious exploration program, the Ministry of Petroleum plans to have over 120 active rigs by 1990—more than double the current number.

The government almost certainly will need substantial foreign assistance if it is to come close to its targets. Evidence compiled by the contractor suggests that the domestic Indian oil industry will have a difficult time doubling the number of rigs and operating them efficiently enough to triple exploratory drilling. Indigenous drilling capabilities are poor by US standards, and a strong tendency toward centralized micromanagement hinders efficient employment of India's existing fleet of rigs. The state oil companies missed their onshore drilling targets in FY 1984 by more than 25 percent and offshore targets by about 30 percent.

In addition to inefficient use of the rigs currently in operation, India is unlikely to be able to increase the number of active rigs much over the next few years. Most new rigs are only replacing old ones, and this situation is likely to continue for some time because of the age and poor condition of the existing rigs. Government documents show a cutback in funds requested by the Ministry of Petroleum for the seventh five-year plan from $1.8 billion to $1.1 billion. Even if the rigs were available, the contractor's evaluation of past drilling performance indicates that experienced personnel would not be available to man and manage them, and support services would be insufficient to back them up. 25X1 25X1

The Indian oil industry also will have a difficult time locating new oil deposits that are likely to be in complex geological formations rather than in more easily identifiable ones. Locating these subtle formations will require detailed seismic surveys and a large increase in seismic data processing at a time when India already has a several-year backlog of unprocessed seismic data. The Oil and Natural Gas 25X1

Figure 7. India will have to drill more wells on shore to meet the government's production goals.

Commission (ONGC) has limited data-processing capability and is reluctant to release the data to foreign contractors for processing, 25X1
Once small geological formations containing 25X1
oil are found, sophisticated drilling and well servicing, completion, and production techniques—now only available from foreign contractors—will be required to make them profitable. 25X1

Western Contractor Participation

India probably will be unable to attract sufficient foreign participation in drilling or acquire enough sophisticated oil industry technology to achieve its production goals. 25X1
India's efforts are being hamstrung by the vacillating policies of the Ministry of Petroleum and the relatively poor terms being offered to contractors. Although the Ministry of Petroleum has successfully encouraged the formation of 15 joint ventures during FY 1984 and FY 1985 between foreign drilling companies and private Indian partners, and these 15 ventures have already bid on ONGC tenders for drilling services, Indian restrictions guarantee that many of the newly formed joint ventures will never drill in India. Once the bids were submitted, the ministry announced that the mere provision of rigs or other equipment could not be construed as equity in the ventures and that such joint ventures would have to procure all their equipment through competitive global bidding without preference to the foreign partner. 25X1

On the basis of current low oil prices and the disappointing experience of foreign oil companies, the contractor believes the limited size and widespread distribution of remaining petroleum resources also will limit the willingness of contractors to risk their financial resources to explore for oil in India. Most potential oil deposits do not appear to offer a return large enough to satisfy the central government and cover the costs of private contractors. Many firms probably have written off participation in India as not economically feasible because of the low expected payoff as well as the difficulty in working with the Indian Government. A US oil company that drilled only dry holes in one of India's best potential areas adjacent to Bombay High and other firms that have 25X1

drilled offshore areas in the past are not likely to return to India without clear prospects for oil discoveries. The reduced budgets of Western oil companies for exploration prompted by low oil prices also are a strong limiting factor on foreign oil company interest in India.

Nonetheless, India is making a strong effort to attract bidders. The members of the Indian delegation to the Offshore Technology Conference in May 1985—consisting of ONGC president Colonel Wahi, ONGC member Dr. A. K. Malhotra, and other top officials—had as their first priority discussions with prospective bidders to find out what terms would be required to ensure a successful lease offering, according to attendees at the conference. The government has tried to take account of its findings in its recent invitation to foreign companies to explore for oil and gas in 27 offshore blocks. New liberalized terms include a greater share of oil production for the foreign operating companies, no royalty payments to India, and the elimination of minimum spending commitments or bids. Foreign companies have until 30 November 1986 to submit bids.

Soviet Participation

Thirty years of Soviet involvement in the Indian oil industry will hamper New Delhi's efforts to incorporate more Western technology and techniques. Soviet and Western equipment and methodologies are not always compatible, making a change slow and inefficient. Many in the Indian bureaucracy are reluctant to change from known patterns, while others believe that the Soviet Union is a more reliable partner.

Nevertheless, on the basis of New Delhi's interest in acquiring more Western technology and Moscow's domestic oil problems, the contractor argues that Soviet influence and participation in the Indian petroleum sector probably have peaked. The experience of exploiting the offshore Bombay High field has brought Indian managers and key technical personnel into close contact with Western firms having superior equipment, materials, and technology. The Soviets, in contrast, have little experience with offshore petroleum technology and have little to offer India in this important area.

Soviet overseas technical assistance missions use inferior equipment and their least qualified technical personnel. 25X1

Onshore projects designed and implemented under the auspices of the World Bank have demonstrated to the Indians the technical efficacy of Western state-of-the-art well-servicing and stimulation techniques. If ONGC cannot afford the outlays involved in having these services performed by Western contractors, it probably will try to develop the technology domestically. 25X1 25X1

Still, Soviet influence and participation in the Indian petroleum industry is evident at all levels of operation, from India's use of Soviet-style estimates of reserves and resources—conducted by Soviet-led teams—to onshore drilling and production operations using Soviet methods. Soviet influence is enhanced because many Indian engineers and managers are Soviet trained, several have married Soviet citizens, and they travel frequently to the Soviet Union. 25X1

Agreements with the Soviets allow India to expand oil exploration relatively cheaply. Under a protocol signed with the Soviets in February 1986, the Soviet Union will carry out intensive integrated exploration over the next 10 years in 5,100 square kilometers of the Cambay Basin in Gujarat and 3,100 square kilometers in the Cauvery Basin in Tamil Nadu. The agreement calls for preparation of a detailed feasibility report, execution of geophysical surveys, processing and interpretation of data, drilling of exploratory wells, and preparation of development schemes. The US Embassy in New Delhi reports the Soviets have allocated a credit of 300-350 million rubles at 2.5 percent interest to cover 70 percent of the project cost. A previous commitment by the Soviets included two workover rigs with Soviet crews to rehabilitate 120 wells in the Cambay Basin during 1983-85. 25X1 25X1 25X1

Onshore Production Potential

The contractor estimates that insufficient oil will be found on shore to forestall production declines in the

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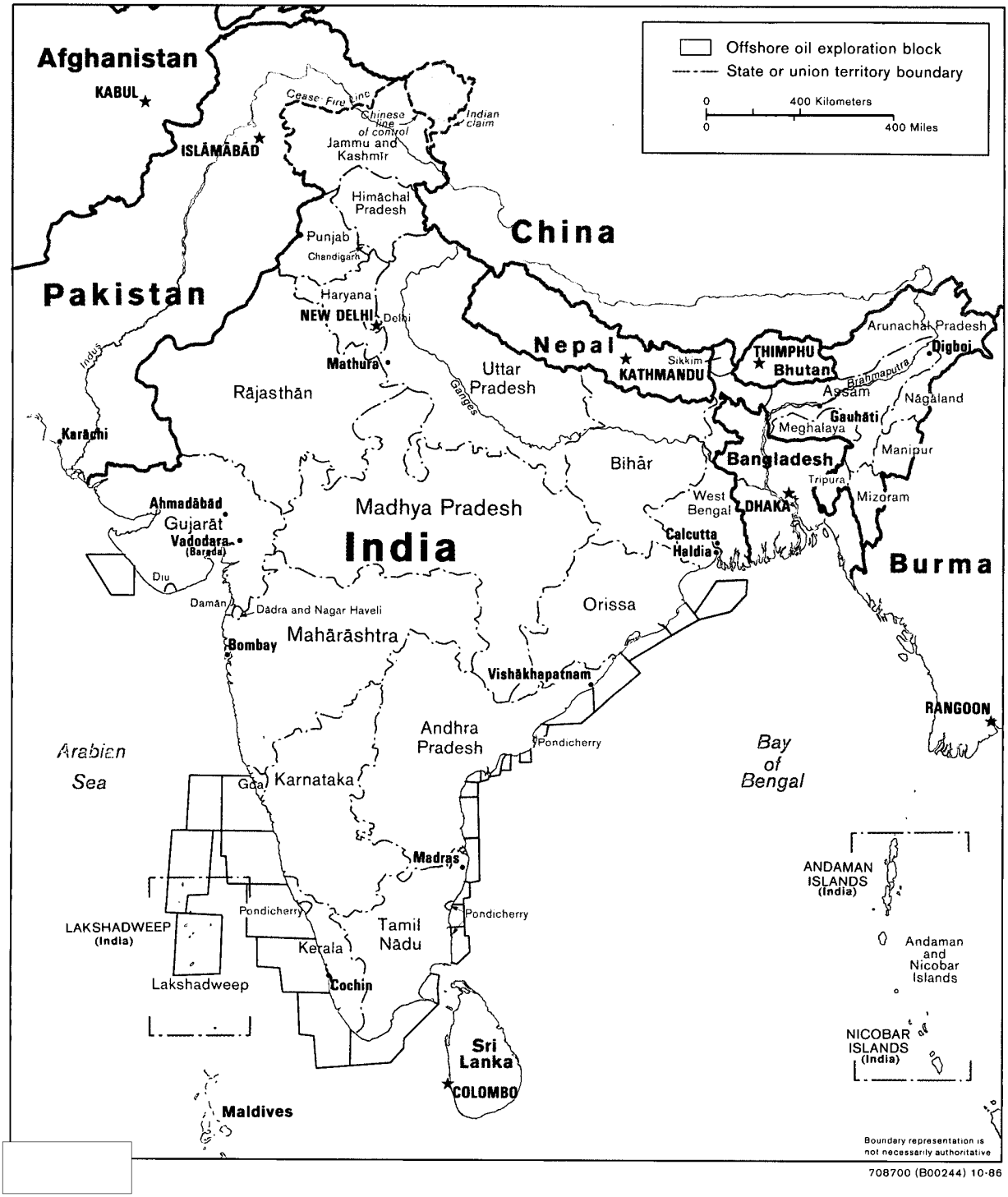
Figure 8
Indian Offshore Oil Exploration Blocks



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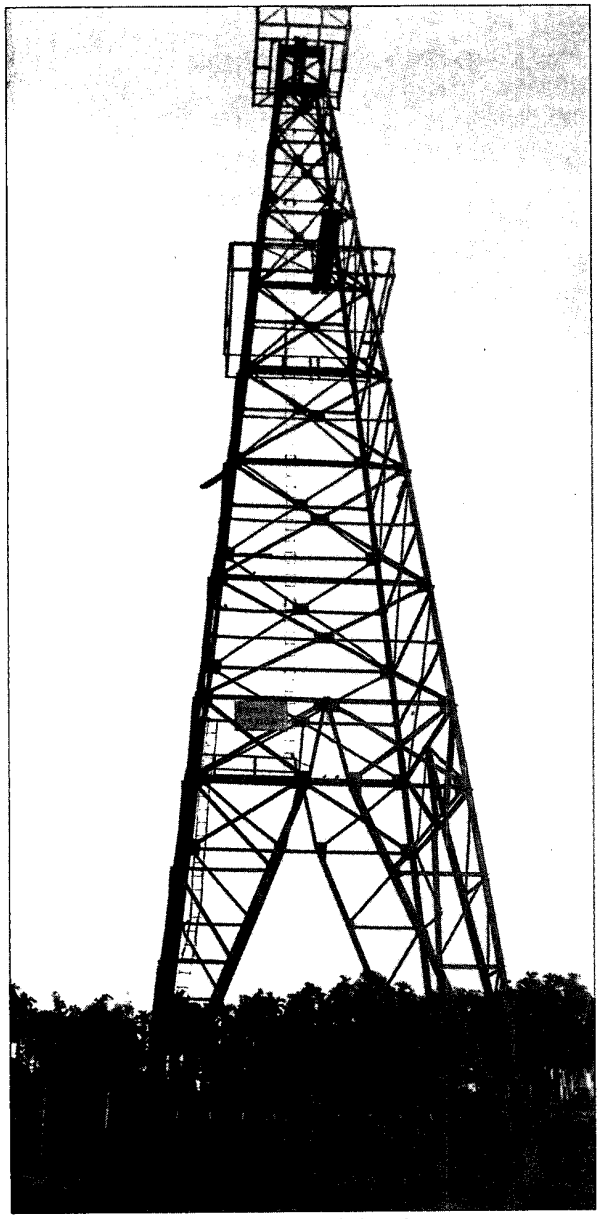
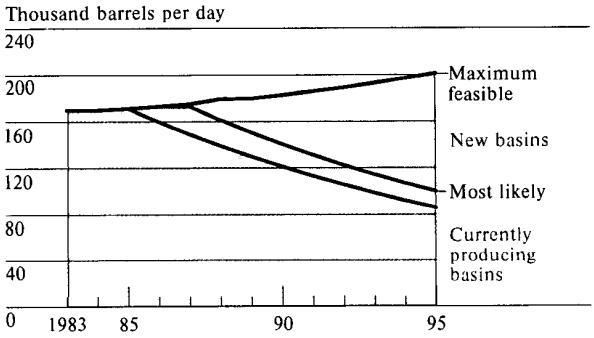


Figure 9. Some of India's oldest fields have been producing for more than 30 years.

Figure 10
India: Contractor's Estimate of Onshore Crude Oil Production Potential, 1983-95



Source: Contractor study.

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next five years, given the size and nature of undiscovered recoverable reserves. India's petroleum discoveries in the last decade barely kept pace with the amount of oil produced. Significant reserve increases claimed by the Ministry of Petroleum since 1980-81 are attributable primarily to improved oil recovery estimates rather than new discoveries. Special enhanced oil recovery techniques only serve to slow the rate of decline in existing production over the next 10 years.

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The maximum feasible onshore crude oil production India can attain over the next decade, according to the contractor's analysis of the geologic potential, is 200,000 b/d, only a slight increase over current output instead of the 80,000 b/d increase being projected by the Indians. The most likely scenario, however, shows onshore production declining rapidly after FY 1987 to about 100,000 b/d by FY 1994. Discoveries in new areas can be expected to contribute no more than 25,000 b/d in FY 1987 and decline to about 14,000 b/d by FY 1994. We believe this estimate is optimistic because it assumes that discoveries in new areas will be brought on stream continuously and without delay.

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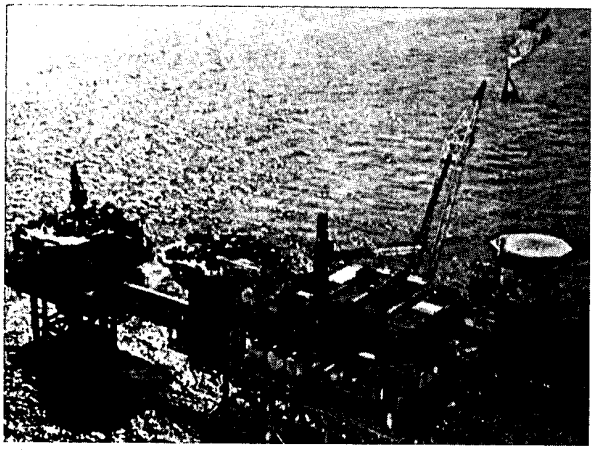
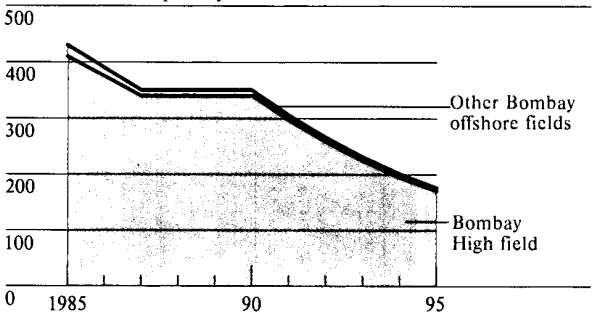


Figure 11. The Bombay High will continue to be India's most important oil-producing area.

Despite an active exploration effort in recent years, there has been a notable lack of commercial success in new areas on shore. Estimated undiscovered recoverable reserves in these areas are too small and too dispersed geographically to warrant crediting them for a significant assured production in the next decade, according to the contractor's review of the geologic potential. If the Indians were to substantially upgrade the efficiency of their operations and produce from existing reserves at a faster rate, the decline could be postponed temporarily, but probably only at the expense of a more rapid decline later.

Special schemes to improve the recovery from known oil deposits have been considered by ONGC to boost onshore oil production. In the Cambay Basin, for example, two thermal pilot projects and a chemical pilot project have been proposed. Special enhanced recovery methods probably will not materially affect India's oil production in the next 10 years because the methods proposed by India so far have not proved commercially viable. Even if pilot tests are successful, the leadtime required to analyze the results and to design and implement a fieldwide project make it unlikely that these methods can be implemented by India on a field scale within the next 10 years. Moreover, even if India were successful in applying special recovery schemes, the contractor's analysis shows that recoverable reserves are too small to make a significant impact on production.

Figure 12
India: Contractor's Estimate of Offshore Crude Oil Production, 1985-95



Source: Contractor study.

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Offshore Production Potential

The contractor's review of the geology and exploration already undertaken indicates that offshore crude oil production over the next five years will depend almost exclusively on production in the Bombay High field. The Bombay High field will continue to dominate output because of the poor prospects of finding more recoverable offshore reserves, the small sizes of remaining undrilled structures, and the poor characteristics of the smaller fields in the remainder of the Bombay High area. The government is producing from two of the smaller marginal fields in the area—Ratna and Heera—and is evaluating the economic prospects of producing from eight others.

The contractor evaluation of offshore production shows a decline from slightly more than 400,000 b/d in FY 1984 to about 350,000 b/d in FY 1987, stabilized output through FY 1989, and a decline thereafter to about 175,000 b/d by FY 1994. This contrasts with the Indian Government's assessment that it may be able to increase offshore production

15,000 b/d by FY 1989.

The estimate also accords with the experience in offshore fields around the world that have been produced under the duress of either meeting national energy requirements or earning a profit in exceptionally capital-intensive oil-producing areas such as the North Sea.

Outside of the Bombay High area, the leadtimes involved in developing new areas off shore almost guarantee that none will be developed through FY 1989. Even beyond FY 1989, prospects for new areas off shore are not bright.

The USGS report indicates that India's most likely remaining offshore potential is less than 1 billion barrels of oil. This is very small considering the large area involved and creates a high risk that no commercial reserves will be found in any given basin. The offshore Krishna-Godavari Basin is a case in point. It was once touted by ONGC and the World Bank as a potential major addition to national petroleum reserves. Yet, to date, the largest field discovered is no more than one-fifth the minimum economic field size of about 100 million barrels.

The contractor's analysis of ONGC's offshore drilling capability, average and incremental well productivities, and other data on the Bombay High field indicates that the peak production rate achieved in the field—400,000 b/d—does not represent drilling or facilities constraints. The contractor estimates that the field could reach a production level of more than 500,000 b/d. Nevertheless, it is clear from the many references by Indian officials to the fact that Bombay High production has peaked that New Delhi does not intend to continue producing at such a high rate. The contractor believes that India has decided against higher rates of production because this would lead to premature water and gas encroachment, substantial loss of recoverable reserves, and rapid field production decline.

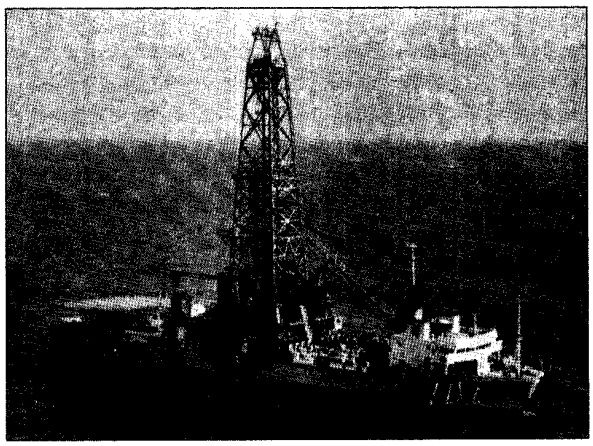


Figure 13. A drillship owned by ONGC continues the search for oil.

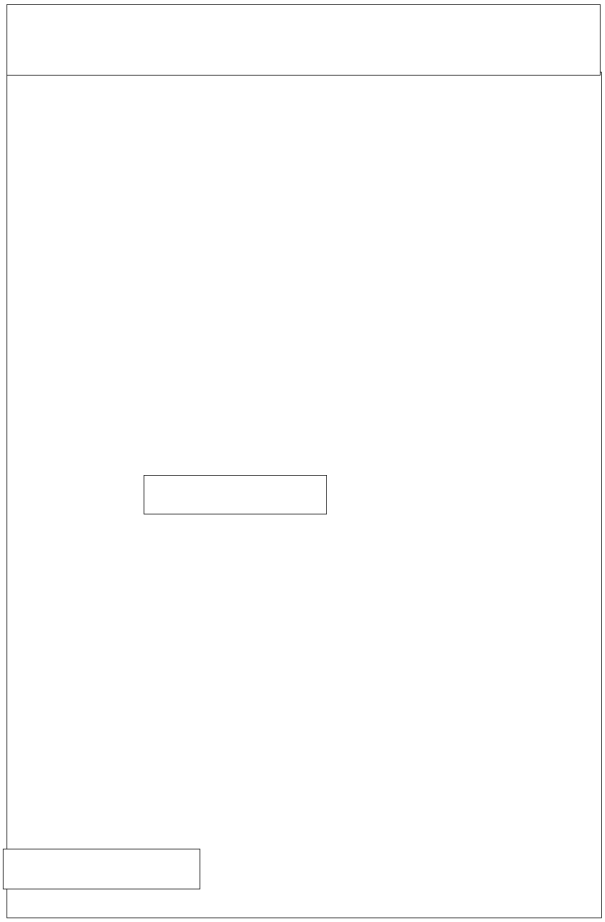
Prospects for Smaller Bombay Offshore Fields

the satellite offshore fields—eight small marginal fields [6] in the area surrounding the giant Bombay High field—are not likely to be developed in the foreseeable future because of current low oil prices and the poor prospects for significant production.

we believe the much lower oil prices that have been observed in recent years will lead to at least a temporary shelving of most projects.

Even if the fields were developed, production would be inconsequential in terms of national output.

[6] Marginal fields in the offshore environment are those not sufficiently profitable for installation of permanent production facilities.



Natural Gas Prospects

In the contractor's judgment, natural gas output should exceed 1 billion cf/d by FY 1989. Output from an offshore gasfield scheduled to begin production in the next year will more than compensate for the expected decline in offshore associated gas. Onshore natural gas output will probably remain relatively stable through the mid-1990s. Gas-oil ratios of mostly onshore associated gas production will rise slightly, offsetting the effect of oil production declines.

Development of the giant South Bassein gasfield discovered in the Bombay offshore area in 1976 is under way. As of mid-1980, seven exploration wells had been drilled on the South Bassein structure. The field is now estimated to contain recoverable reserves of 7 trillion cubic feet of gas, about 1.2 billion boe.

The estimated plateau production rate of the field is about 700 million cf/d when fully developed. This is a fairly conservative rate, but it is designed to provide stable field production over a 20-year period because of the need for long-term production to supply dedicated consuming facilities.[7]

Development of South Bassein gas reserves is now well advanced after having been postponed for several years—most recently because of the discovery that the gas contained corrosive hydrogen sulfide, requiring respecification of all offshore handling facilities for sour gas service. ONGC will conduct drilling and pipelaying operations on its own, with little or no help from outside contractors.

The first of three planned phases of field development started in September 1985 and is scheduled to be completed this year with a production capacity of 350 million cf/d. The first phase will consist of four platforms, one each for production, utilities, flaring, and living quarters. The production platform will have seven gas wells. Two of the seven wells will be reserved for prolonged testing of the oil zone, but there are no plans to produce oil. The second phase also will have a production capacity of 350 million cf/d and is scheduled to begin producing in April 1988. By 1989, with the addition of two more remote well platforms in Phase 3, the field should be producing at a plateau rate of 700 million cf/d, assuming transportation and consuming facilities are completed as scheduled.

South Bassein gas will be brought on shore through a 36-inch subsea pipeline to Hazira, the starting point for the major Hazira-Bareilly-Jagdishpur trunk pipeline. A French-Japanese consortium was awarded the

[7] The South Bassein gasfield also has an oil column 3 to 5 meters thick, which contains about 1.4 billion barrels of oil. A reservoir engineering firm hired by ONGC to assess the field's reserves estimated that only about 5 percent—70 million barrels—would be recoverable. The recovery rate is low because of the thinness of the oil column and underlying water, which probably will quickly invade the production stream. Water encroachment also could substantially reduce recoverable gas reserves. If ONGC decided to recover the oil, the contractor believes the maximum achievable production rate from the field would be no more than about 18,000 b/d.

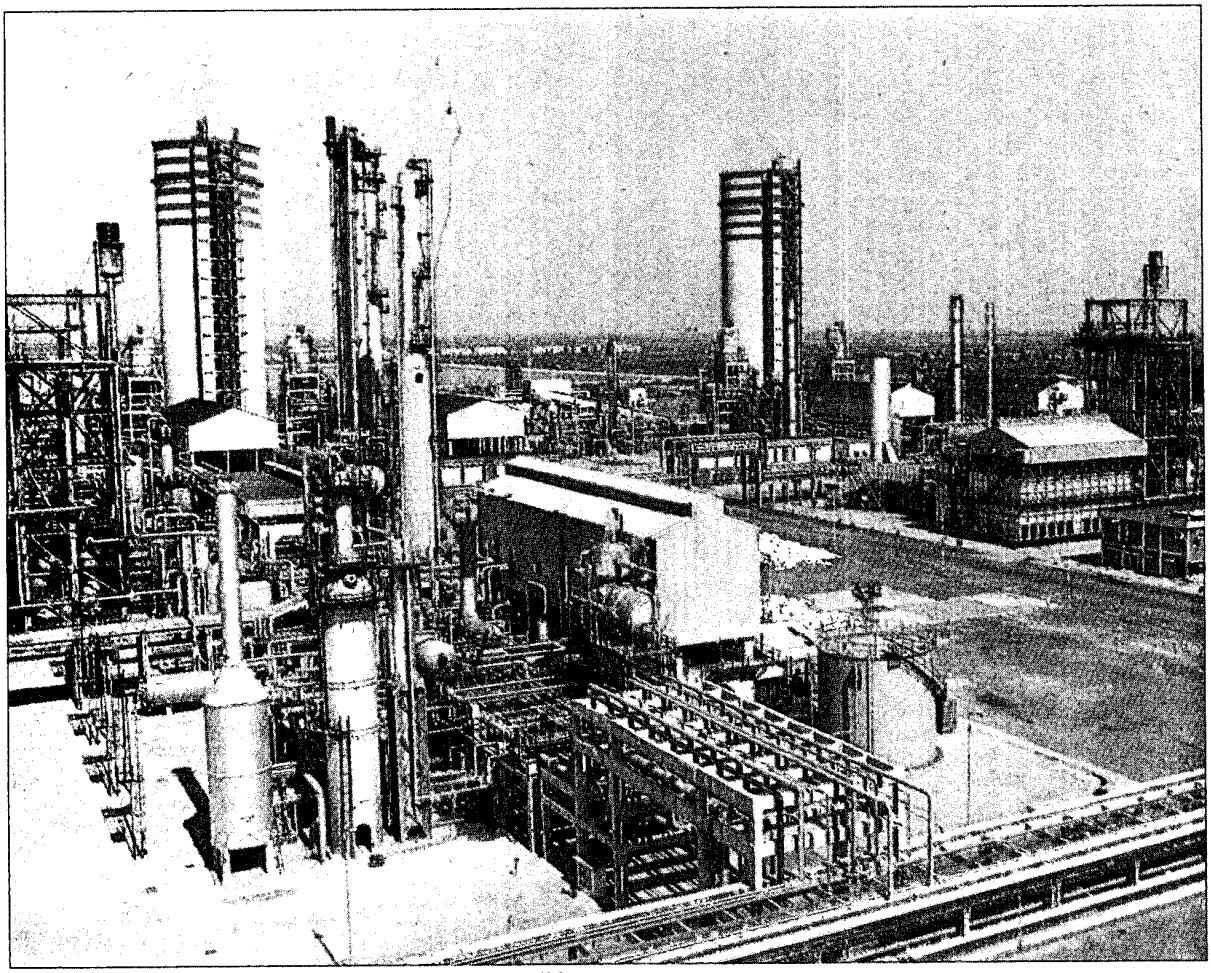


Figure 14. Most of the gas produced from offshore fields will be used in gas-based fertilizer plants.

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$1.6 billion contract to build the line in April 1986, after more than two years of negotiations, by offering a package that included concessionary financing to help meet the foreign exchange costs and substantial participation by Indian companies. When completed in 1989, the line will run 1,800 kilometers through Maharashtra and Madhya Pradesh and terminate in Uttar Pradesh at Babrala (near Bareilly), with a major branch running southeast to Jagdishpur, not far from Lucknow.

Six natural-gas-based fertilizer plants, now under construction or on the drawing board, will be built at various points along the line. Two other fertilizer plants will be supplied with gas directly from the Hazira terminal.

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Without major new investment, however, the government is unlikely to have sufficient gas to supply three power plants and two refineries planned for operation in the late 1980s and early 1990s. Natural gas planners had envisaged accelerating the development schedule of marginal Bombay offshore fields and producing all of them at maximum feasible rates. Production from this area would have provided the additional gas supplies for the new plants. With the

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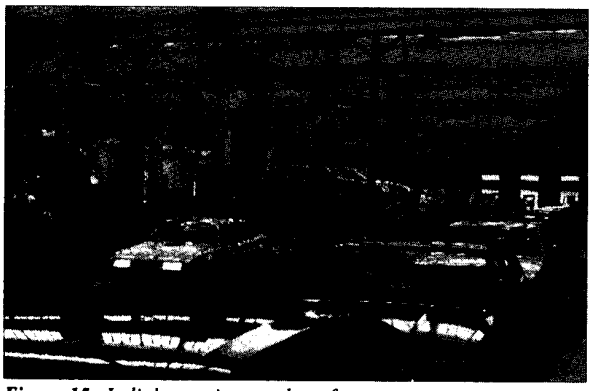


Figure 15. India's growing number of passenger cars will boost oil consumption.

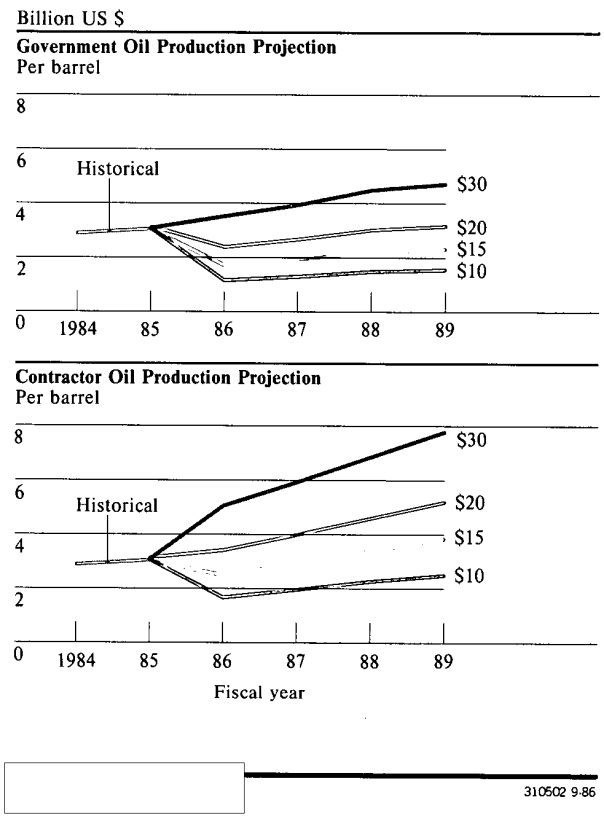
cutback in government funds available to the petroleum sector, the marginal Bombay offshore fields probably will not be developed, and the power plants and the refineries will be delayed and may not be built.

Implications for India's Economy

We believe the deteriorating prospects for increased crude oil production will have a serious adverse impact on India's economic growth if world oil prices rise much above current levels. New Delhi will have to increase oil imports to meet domestic needs or bring in more foreign oil company services to sustain output. Either option would increase the oil sector's need for foreign exchange and deny New Delhi these funds for other development-related projects.

Recent trends point to demand for petroleum products growing by at least 7 percent a year, slightly above the government projection of 6.4 percent. The volume of petroleum imports is almost certain to increase faster than the 8-percent average annual growth projected by the government, particularly as Prime Minister Gandhi pushes for faster industrial growth. Liberalization measures are making more automobiles available, many manufacturers are using diesel generators to maintain production when electricity from the public grid fails, and many farmers have turned to diesel pumps for irrigation.

Figure 16
India: Oil Import Costs, FY 1984-89



Increased oil imports will offset India's savings from lower world oil prices. If India's crude oil demand reaches 1.2 million b/d by FY 1989, the oil import bill using the contractor's estimate of production and a sustained world oil price of $10 to $15 per barrel would be $2.6-3.9 billion. India's oil import bill in FY 1985—with crude at slightly less than $30 per barrel—was about $3.1 billion. We believe declining oil production will add to India's financial gap in FY 1989 unless oil prices remain near the $10 per barrel level.

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Implications for the West

India's desire to find more oil reserves and get maximum recovery from producing fields will present Western countries with a potential market for the sale of high-technology goods and services. Offshore exploration, particularly in deep waters, will require expertise and technology that India does not possess and the Soviets cannot provide. The onshore search will require sophisticated oilfield services, particularly in seismic analysis, to find the small deposits that undoubtedly exist but are hard to detect. Special oil recovery techniques contemplated by India to maximize output from known fields will also require the assistance of outside experts. 25X1

The foreign payments impact of constant or falling oil production, however, will make it more difficult for New Delhi to increase purchases of Western oilfield equipment and services and other high-technology and capital goods needed to modernize the economy. India probably will seek more Western aid and concessional financing to finance oil exploration and development. 25X1

The Soviet Role

The Soviet role in the Indian oil industry should diminish. India will continue to look to the Soviet Union for inexpensive and basic oil exploration assistance, but we do not believe the Indians expect much assistance in high-technology areas. Moscow has little experience in offshore production, particularly in deep water. The level of its onshore exploration capabilities and the availability of sophisticated services from the USSR also are limited. Moscow's problems in maintaining domestic oil production and its requirements for oilfield services and skilled oilfield workers in its domestic industry will also make it difficult for the USSR to increase its role abroad. The Soviets already have declined an Indian invitation to explore the onshore West Bengal Basin or areas in the Himalayan foothills, according to press reports. 25X1

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Appendix A

Difficulties in Interpreting Indian Petroleum Reserves Data

The method used by India to classify its petroleum reserves is borrowed directly from the Soviet system. The Indians have six categories of reserves—A, B, C1, C2, D1, and D2—which are differentiated according to the degree of certainty concerning their existence and recoverability. "A" reserves are drilled and producing, while "D2" reserves are almost completely hypothetical with only the sparsest data to back them up. The six categories are divided between "balance" reserves (A, B, C1) (so named because they are entered on a balance sheet), which are completely or largely identified, and "prognosticated" reserves (C2, D1, D2), which are based on extrapolation and speculation about new areas and enhanced recovery potential.

Balance Reserves

India's system does not correspond exactly to either the Soviet or Western systems and thus leads to uncertainty when comparing to either proved or probable reserves in other systems. The Indian Ministry of Petroleum officially reports "proved and indicated balance recoverable" reserves, which contains all A, B, and C1 reserves. This differs from the Soviets, who include only 10 percent of C1 reserves in their balance and count the remaining 90 percent of C1 reserves as prognosticated reserves. It also differs from Western definitions in which A plus B reserves are very close to proved reserves.

India's reporting of balance reserves is often described in Western terms by the Indian press or other observers as "proved and probable reserves" or "proved reserves." This is misleading because Indian proved and indicated balance recoverable reserves are more inclusive than Western proved and probable reserves, although by how much is impossible to determine. The contractor could find only one instance in recent years—1978—when the Indians released disaggregated estimates of proved and indicated balance recoverable reserves. As a result, almost no direct information is available about the breakdown between what are proved reserves and can be used for production planning and forecasting over the next several years, and what are probable or possible reserves and might contribute little, if anything, to production prospects—especially in the near term. 25X1

Another definitional problem causing confusion over the Indian reserves classification system arises because it includes information on the amount of total geological reserves of oil associated with recoverable reserves for each category of reserves. Sometimes Indians will refer to total oil reserves simply as reserves or even proved geologic reserves—causing misunderstanding among Westerners who associate the terms proved and reserves exclusively with recoverable oil. 25X1 25X1

India has shown an increasing tendency to overestimate proved and indicated balance recoverable reserves, according to the contract study. In 1980, India claimed offshore oil reserves that were almost equal to the expected ultimate recovery from the Bombay High field as reported in World Bank documents, but, in FY 1983, India raised its estimated offshore oil reserves from 1.75 billion barrels to about 2.5 billion barrels without any new commercial discoveries. Most of the increase was due to an upward revision of reserves at the Bombay High field because of much better than expected reservoir performance to date. In the contractor's judgment, this performance may be due to overproduction of the field and disregard for sound engineering practice and lagging development of field facilities. The contractor believes there is a high risk that recoverable reserves from the Bombay High field will be substantially less than the Indians now estimate. 25X1 25X1

India also is probably including estimates of recoverable oil from the application of enhanced (tertiary) oil recovery (EOR) methods at Bombay High in its reserves estimates. Ninety percent of the 750-million-barrel upward revision to official reserves since 1980

was entered into the books in 1981, following the second major OPEC-related oil price rise in 1979, which convinced many observers that no end to rising oil prices was in sight. Although there may have been grounds to speculate in 1981 that tertiary recovery would eventually become economically viable for large offshore fields, today's lower oil prices suggest that this will be unlikely during the next few years.

25X1

The Cambay Basin provides yet another example of problems with Indian reserves data. In 1983, Indian claims of proved and indicated balance recoverable reserves in the basin were increased by 71 percent above the 1982 figure of 385 million barrels to 658 million barrels. This large, one-time revision in reserves—little new oil was actually discovered—probably was made to win World Bank support for the planned Cambay Basin Petroleum Project. More than half of the projected 30,000 b/d peak incremental production associated with the project is to come from enhanced recovery in primarily heavy oilfields. The problems India will have in applying and mastering EOR techniques, in addition to normal economic and technical risks associated with the project, suggest that most of the increase in claimed reserves probably cannot be exploited at today's prices.

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Appendix B

Contractor's Methodology for Forecasting Production

Onshore

The contractor's forecast of onshore oil production is based on an analysis of historical discovery indexes, drilling rates, and reserves-to-production (R-P) ratios because there are virtually no data available on India's onshore fields except what was published decades ago while the industry was still in private hands. India is one of a handful of major oil-producing countries—the others are members of the Organization of Arab Petroleum Exporting Countries—which refuses to provide field production statistics to the *Oil and Gas Journal* for its annual survey of worldwide production. The resource level the contractor used was the USGS's most likely level of remaining recoverable reserves in currently producing basins and undiscovered recoverable reserves in virgin territories.

The contractor's starting point for forecasting onshore production was to compute a discovery index (DI) for onshore India based on a methodology developed by L. F. Ivanhoe in his study of world oil discoveries. Exploration drilling data were pieced together from various sources and compared with increments to reserves. The data yielded a DI for India for the decade of the 1970s of 127 barrels (bbl) discovered per foot of exploration drilling. This compares with a DI of about 3,100 bbl/ft for the less developed countries as a group during the same period, indicating the relatively low "prospectivity" of onshore India. Although Ivanhoe found a consistent pattern of about a 7-percent annual decline in discovery indexes worldwide, the contractor used the DI for the decade of the 1970s without modification along with estimated exploration drilling capability to forecast new discoveries through 1995, thus giving India the benefit of the doubt in future oil discoveries.

The contractor then looked at R-P ratios based on reported data and also created a smoothed time series of reserves using drilling data and discovery indexes. From the reported and smoothed data series, it appears that India's R-P ratio is not likely to fall much below 15, higher than ratios of around 10 achieved in developed countries with mature producing basins, but not unexpected because of the inefficiency of Indian operations. 25X1

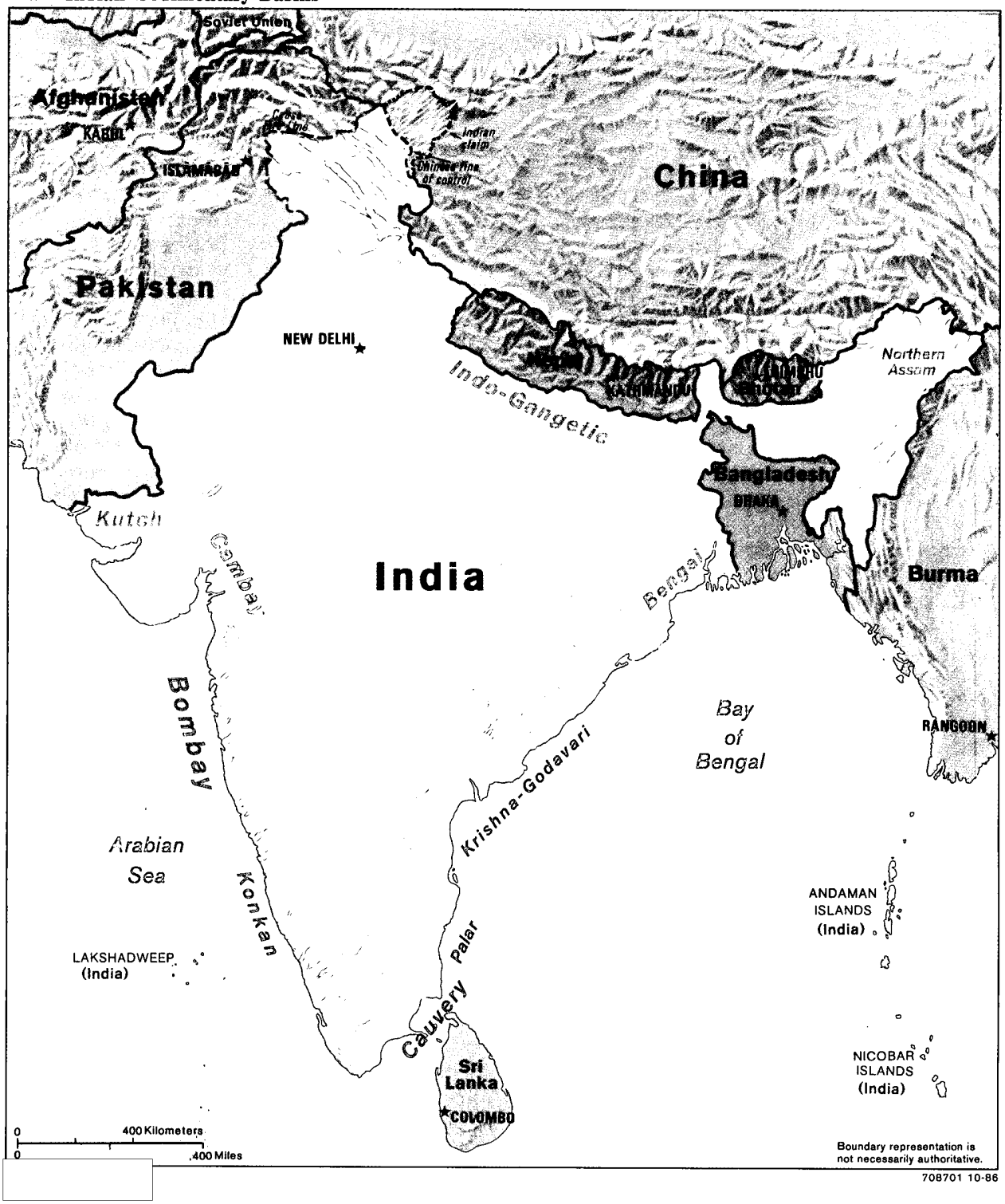
The R-P of 15 was used to estimate production annually through 1995 based on reserves estimates unconstrained by any limit to undiscovered recoverable reserves and made from drilling projections and the discovery index. This is the maximum feasible scenario depicted in figure 10. Output from currently producing basins was projected by limiting available reserves to proved reserves plus the amounts given as the most likely undiscovered recoverable oil by the USGS. The curve in figure 10 identified as "most likely" represents a similar procedure using the USGS estimates of most likely undiscovered recoverable reserves from new basins plus remaining recoverable reserves in currently producing basins. 25X1 25X1

Offshore

The contractor assumed offshore reserves of 2.33 billion barrels and a peak R-P ratio of about 15. This is more realistic than the peak ratio of 17.33 implicit in a World Bank forecast of India's reserves, but perhaps still too high considering experience in other offshore fields and the urgency with which India has pursued Bombay High field development. If the peak R-P ratio were 12, probably an average figure for North Sea development, reserves would be about 1.8 billion barrels. 25X1

Thus, the government's production profile calling for plateau production of about 350,000 b/d, which implies reserves of about 2.2 billion barrels, with a four-year plateau period and an empirically estimated 13-percent postplateau decline rate represents a reasonable, perhaps moderately optimistic, scenario falling between potential high and low reserves estimates. The peak R-P ratio associated with this scenario is about 14.6. It is unlikely that actual production will depart from the forecasted contractor scenario by more than 10 percent in any given year even if ONGC attempts to hold Bombay High production at or near its peak level as long as possible. 25X1 25X1

Figure 17
Main Indian Sedimentary Basins



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Appendix C

The Geology and Potential of India's Major Basins

The Assam Basin

Assam, in northeastern India, produced all of India's indigenous oil and gas before 1960. By FY 1983, Assam accounted for only 19 percent of the country's oil and 33 percent of its gas because of production from new discoveries in western India. According to the Indian Ministry of Petroleum, Assam has 20 percent of the nation's proved and probable recoverable oil reserves and 16 percent of the gas.

The first commercial oil deposits in India were discovered in 1890 at Digboi in Assam. Another major oil deposit also was discovered in Assam at Nahorkatiya in 1953. In addition, according to USGS, four or five fair discoveries and an equal number of smaller discoveries have been made.

The two major existing fields in Assam are at Digboi and Nahorkatiya. The producing zones at Nahorkatiya are thicker than at Digboi but irregular in thickness and area distribution, according to the USGS. Effective thicknesses range from 30 to 210 meters and average 60 meters. The oil is waxy and low in sulfur and generally has a high gravity.

Production in Assam has increased steadily from less than 10,000 b/d in 1960 to current levels of about 100,000 b/d. Output was temporarily reduced by more than one-half in 1980 when sectarian violence caused production problems.

The contractor expects a slow decline in production in the Assam basin over the next decade. Most of the production from Assam, although in declining amounts, will continue to come from the Nahorkatiya field because almost half of the reserves in the Assam basin reside there, according to USGS, and because the smaller Digboi field is approaching old age.

Exploration and Production

The USGS estimates exploration in the Assam basin about 80-percent complete. India has drilled 174 exploratory wells in the basin and an additional 205 development wells.

The contractor believes the Indian Government has assigned a lower priority to exploration in Assam than to western India, especially the Bombay offshore region. According to Oil India Ltd., 70 exploration wells are planned in Assam over a 10-year period, four more than the pace of the past but slow compared with other areas in the world, even mature provinces. 25X1

Production at Digboi is from 24 separate sands. Some of the thicker oils are presently unrecoverable, according to ONGC. Oil is produced primarily by dissolved gas, pressure, and some water and natural gas drives. Experiments with waterfloods were generally disappointing, according to ONGC. 25X1

The Nahorkatiya field, 40 kilometers southwest of Digboi, is quite different. Wells are deeper, with greater spacing and greater per-well production. This is apparently due to the relative youth of the field, compared with Digboi, and the more modern production practices that have been followed at Nahorkatiya. Irregular formation characteristics and pervasive faulting require careful attention to reservoir characterization and development. More than 140 wells have been drilled. Production strategy is designed to prolong primary recovery and to blend the crude produced to meet refinery needs. 25X1

Wells at Nahorkatiya are 2,700 to 3,000 meters deep, but drilling is less difficult than at Digboi, with overall drilling rates exceeding 300 meters per day. Controlled directional drilling has been successful to locations under the Dihang River. 25X1

A few other smaller fields have been discovered, including Kusigan, 25 kilometers southwest of Digboi; Moran, 40 kilometers west-southwest of Nahorkatiya; Lakwa, 20 kilometers south-southwest of Moran; Rudrasagar, 40 kilometers southwest of Moran; and Geleki, 25 kilometers southeast of Rudrasagar. 25X1

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Economic and Technical Constraints

Lack of available large prospects, except possibly in the hostile environment of the neighboring Bay of Bengal, is the major constraint to materially increasing production from the area. Lack of suitable seismic reflectors makes identifying reserves in subtle geological formations difficult, and the complex geological formation is likewise extremely difficult to explore, drill, and develop. Attempts at EOR are under way but have not been notably successful because of the viscous, waxy quality of the oil and the heterogeneous nature of the reservoirs.

Potential Reserves

The Indian Government estimated Assam's proved and probable recoverable reserves at 708 million barrels (bbl) in 1983; the USGS estimated recoverable reserves (1984) at 750 million bbl, of which nearly half (338 million bbl) are at Nahorkatiya. These estimates may be somewhat inflated by overly optimistic recovery factors.

The contractor concluded that well over 90 percent of the recoverable oil in the Assam basin has already been found. The small spread in the estimates of undiscovered oil in the two USGS cases with the highest probability points to the advanced state of exploration in the district.

The Cambay Basin

The Cambay gasfield—a major source of natural gas for India—was discovered in 1958. Commercial oil production from the Cambay Basin began in September 1961, following the discovery of the Anklesvar field, the largest onshore field in India. The Cambay Basin contains more reserves of oil and gas than the Assam oil province, but reserves are much smaller than those in the offshore Bombay High area. Thin reservoirs and the small size of structures limit the amount of additional oil and gas that are likely to be found in the basin, in the contractor's judgment.

Government statistics indicate that the basin produces about 14 percent of the domestic oil and 13 percent of the natural gas in India. Anklesvar contains about half of the Cambay Basin's reserves.

The World Bank evaluation of Cambay Basin fields shows that the extreme variations in the main characteristics reflect differences between the gassy high-gravity fields in the south and the heavy oilfields in the north. 25X1

Exploration and Production

The ONGC considers Cambay Basin to be one of the best explored basins of the country. According to the World Bank, through 1982, 697 exploratory tests were drilled on 134 of the identified oil and gas prospects. The surface mapping of the basin was 25X1
essentially completed by 1983. In addition, 58 percent of the basin has been covered by gravity and magnetic surveys, 66 percent by seismic survey, and 85 shallow test holes have been drilled. The USGS considers exploration in the Cambay Basin about 80-percent complete. The large portion of the area already explored supports the contractor's estimate that major 25X1
new quantities of oil and gas are unlikely to be found. 25X1

Offshore results in and near the southern end of the Gulf of Cambay have been disappointing, including dry holes drilled by a US company in the Saurashtra block. The contractor believes that, because of unfavorable geology in the area, the rest of the Gulf and the shallow near-shore waters are not especially attractive. 25X1

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Oils in the Cambay Basin are reported to be generally very waxy. The heavier oils probably resulted from the degradation of original lighter oils by bacteria or by oxidation by ground waters. Heavy oils are more common in the shallower fields and in the northern part of the basin. Exploration and development have been aimed toward the light oils, leaving the heavy oilfields in the northern part of the basin relatively 25X1
undeveloped, pending decisions to attempt more expensive heavy oil recovery methods. 25X1

The Anklesvar field covers about 26 square kilometers. The World Bank reported that cumulative production through August 1983 was about 370 million 25X1
bbl; current production is about 30,000 b/d, down from 60,000 b/d in 1968. Oil is produced from 11

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sandstone zones at an average depth of about 1,100 kilometers. About two-thirds of the production comes from three reservoirs near the top of the producing zone. Remaining recoverable reserves are expected to be about 72 million barrels, or about six and one-half years of production at the current rate.

The Anklesvar reservoirs have good natural water pressure to assist in production. Since oil and water mobility is almost equal in the reservoir, the World Bank projects ultimate recovery at an exceptionally optimistic 53 percent of the original oil in place. Water injection was started in 1963, and water produced with the oil averages about 40 percent of the total. In 1984, of 196 production wells that had been drilled, 90 produced oil, seven produced gas, 15 were watered out, and 84 awaited workover and installation of artificial lift. In addition, there were 29 injection wells used to inject water to stimulate production, and 21 other wells had been abandoned. The contractor believes there is little chance of increasing reserves at Anklesvar or of even reversing the production decline because most of the areas have been thoroughly tested.

The Cambay field has two oil- and gas-bearing zones, an upper gas zone at 1,600 meters and a lower undeveloped tight oil zone at 2,000 meters. The World Bank reports that about half (53 billion cf) of the original recoverable gas reserves have not been extracted. Production has been declining, but new drilling is expected to increase gas production somewhat. The Bank reports that, of 55 gas wells that have been drilled, 20 have been abandoned because of water encroachment, another 10 will be abandoned by this year, and the rest will probably have to be abandoned within six to seven years.

Because the light oilfields are relatively small and have little prospects for expansion, the heavy oilfields of Santhal, Balol, and Lanwa probably present the only possibility for increasing output. Schemes for EOR have been proposed to increase substantially the production and ultimate recovery from these fields. Only Santhal of the heavy oilfields, with 41 producing wells, has been developed to any extent; production there is about 4,800 b/d. A plan to drill 44 wells in the northern section of the field would create another 4,900 b/d of capacity, according to the World Bank.

Economic and Technical Constraints

Physical constraints such as small and widely distributed fields, geological problems, and a low hydrocarbon content of the oil and gas fields reduce the promise of the Cambay Basin. The large number of small fields makes logistics, such as gathering line systems and treatment facilities, more expensive and makes it more difficult to achieve acceptable efficiency. Gas collection from the large number of small fields will also be difficult. High reservoir permeabilities and active water drives make water encroachment a problem, and this is worsened by irregular reservoir configurations. Pressures in the geologic structures require good engineering and special precautions in drilling and production. There is a risk of formation damage in low-pressure fields such as Cambay and blowouts in high-pressure reservoirs such as Anklesvar.

ONGC's field operations in the Cambay Basin are plagued by serious problems. The company uses obsolete and wornout equipment and faces a serious shortage of rigs to rehabilitate wells and install pumping equipment. The increased use of pumps needed for water injection and for production will require more electric power than is now available. The fields also require improved oil well cements and cementing practices and better drilling muds, mud engineering, and mud testing equipment to deal with difficult strata and pressures.

About 10 percent of the original oil in place in the basin is estimated to be heavy (that is, gravity below 18, API). Primary production of the heavy oils is expected to be only about 5 percent of the oil in place, and enhanced recovery will be needed to economically justify producing the heavy oilfields. Recoverable heavy oil may total 4.5 million bbl in primary production and 18 million bbl with enhanced recovery. Total basinwide recoverable heavy oil is thus about equal to the amounts recoverable in some of the smaller light oilfields.

State-of-the-art enhanced production operations—such as massive hydraulic fracturing, polymer treatments, and in situ combustion—will be needed to

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produce the heavy oils and to maximize production from the light oilfields. These sophisticated and high-cost techniques are not being used in India because of lack of equipment and inadequate indigenous technical expertise.

Potential Reserves

The resource potential of the Cambay Basin varies greatly depending on the proportion of the original oil and gas in place that is assumed to be recoverable. Estimates vary from as low as 5 percent in the heavy oilfields to as much as 53 percent in the light oil-bearing Anklesvar field. The World Bank staff uses a basin average of 28-percent recovery of the original oil and gas in place, which the contractor believes is probably on the optimistic side.

Industry studies show that, worldwide, 65 to 80 percent of the ultimately recoverable reserves in any basin are in the five largest fields. An optimistic view, assuming that 65 percent of the reserves have already been found in the five fields, would yield 1,092 million bbl of original recoverable reserves. Since 421 million bbl have already been produced, 671 million bbl discovered and undiscovered remain. By comparison, estimated proved reserves of 500 million bbl plus the USGS "most likely" estimate of undiscovered oil equal 650 million bbl.

The contractor estimates that 80 percent of the basin reserve has already been discovered in the five largest fields. On the basis of this estimate and the mature stage of exploration, the contractor believes that only small amounts of additional oil will be found in the Cambay Basin.

Bombay Offshore Region

The Bombay offshore basin is the only basin on the continental shelf of India that has proved and economically viable production of oil and gas. The contractor estimates that production in the Bombay offshore area peaked at about 420,000 to 430,000 b/d in late 1984, and production is now declining. Two of the 10 marginal fields that India has discovered in the area are producing small quantities of oil. The contractor believes that ONGC's experience with developing these two small fields has dissuaded it from proceeding with development of the remaining eight. Even if development of all eight remaining fields were to begin immediately, the contractor believes the decline in offshore production could not be arrested. In addition, the contractor does not believe new discoveries made in the area will offset the decline.

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Exploration and Production

The Bombay High field is the only truly significant find in over 20 years of exploration of India's offshore areas. The contractor estimated original oil in place of about 7.5 billion barrels. The structure was discovered by a Soviet reflection seismic survey in 1964, detailed with seismic surveys by CGG of France in 1972, and drilled in 1974.

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The contractor used the petroleum industry measurement that the maximum annual production rate from a field should be 1 to 2 percent of original oil in place. Considering the intensity of production activity at the Bombay High field, it is reasonable to expect the annual production rate to peak at 2 percent of original oil in place. The contractor's estimate of peak production rate of 410,000 b/d at Bombay High is equivalent to 2 percent of the estimated original oil in place of 7.5 billion barrels.

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The announcement by ONGC of plans to double the number of platforms in the Bombay High field substantially reduced the contractor's uncertainty about future production potential. The addition of new wells resulting in reduced well spacing will allow ONGC to cut back well flow rates, while maintaining planned overall field production. The contractor believes that, without this drilling program, ONGC will run a high risk of premature water intrusion and potential collapse of production rates. Neither ONGC nor the Ministry of Petroleum can afford to take this risk. Despite budget cutbacks, the contractor expects ONGC to proceed with plans for the new drilling program at Bombay High as its top priority.

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The contractor believes India will be relatively successful in recovering oil from the Bombay High field.

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estimated an ultimate recovery

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factor of 31 percent—considerably higher than the 26-percent factor estimated [redacted] The higher recovery estimate is used by the contractor because of production performance to date [redacted] When the contractor applied a recovery factor of 31 percent to the estimated oil in place of 7.5 billion barrels, ultimately recoverable reserves would then be about 2.33 billion barrels. In the absence of detailed field performance and reservoir data, the contractor used this estimate of field reserves as an input with other known and estimated data for his forecast of offshore production potential. [redacted]

Outside of Bombay High, the South Bassein gasfield is the largest structure in the area. South Bassein is scheduled for initial production in late 1986, pending completion of offshore facilities and a pipeline to shore. The unusually thick section of overlying rock at South Bassein forms a good gas-producing reservoir. [redacted]

[redacted] in addition to Bombay High and Bassein, the best remaining offshore oil prospects in the area include Panna, Heera, Ratna, and Bombay High East (BHE). Oil production has started at Heera and Ratna. [redacted]

A US oil company abandoned its concession after drilling three tests to over 3,000 meters in the Saurashtra offshore area 80 to 100 kilometers northwest of the Bombay High field. This is the only drilling by a nongovernment agency in the offshore Bombay area and the only such private tests in India in many years. [redacted]

Economic and Technical Constraints

Most of the operating constraints of the offshore Bombay area can be overcome with state-of-the-art technology, although the five-month monsoon season hampers offshore construction and pipelaying. The high wax content and poor viscosity of the offshore Bombay oil require special handling with heating, de-emulsifiers, or dilution with lighter oils to transport it. Production and operating costs are also high because the reservoir is thin and covers a large area. Only four wells can be placed on each platform in contrast to the 12 or more common in the North Sea, the US gulf coast, and elsewhere. [redacted]

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Potential Reserves

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Altogether, 39 structures in the Bombay offshore area have been explored by drilling. Some oil or gas was found in 19 of the structures. Another 134 structures have been delineated, according to ONGC records, but all of the untested structures are small. Many have only one-half to one-tenth of the area of the small fields near the Bombay High field. The contractor believes ONGC has tested the best possibilities and has been able to determine which structures have promise. On the basis of experience to date, the contractor believes that further drilling in other areas is not warranted. [redacted]

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The "most likely" USGS estimate of undiscovered oil, 1 billion bbl, would indicate that a little more than two-thirds of the recoverable oil in the offshore Bombay area has already been discovered. The contractor believes the USGS estimate may be unduly optimistic on the basis of experience in similar basins around the world. The estimate assumes that two-thirds of the undiscovered hydrocarbons lie in the Bombay High field and that they are probably 55 percent gas and 45 percent oil on a barrel of oil equivalent basis. The contractor believes available seismic information, the thin pay zones with variable porosity, and the complex faulted structural settings indicate that the conservative (95-percent probability) USGS estimates that 90 percent of the oil and 85 percent of the gas have already been discovered in the offshore Bombay area appear to be more realistic and in line with experience in other similar basins. [redacted]

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The USGS report estimates exploration offshore Bombay to be 55-percent complete, but available seismic structure maps indicate that about 90 percent of the area within structures large enough to contain producible reserves has already been examined by drilling.

One problem with the USGS estimating method is that it extrapolates from known information, and, in the case of the Indian west coast, the extrapolation is from the best-known area, the offshore Bombay, and the early discovered Bombay High. The Bombay High field, however, is the only very large structure offshore Bombay, according to available seismic structural information. The dry holes drilled on many promising structures and the small size of remaining undrilled structures in the area indicate to the contractor that the USGS's "most likely" estimates are too high. In any case, development, if started now, assuming a new find, will not mature into sustained production until late in the century at the earliest.

Krishna-Godavari Basin

India's ONGC has identified the Krishna-Godavari Basin on the eastern side of India along the coast of Andhra Pradesh as the most promising new area of both onshore and offshore petroleum potential outside the Bombay High. The World Bank agreed to loan India $166 million, 30 percent of expected Krishna-Godavari exploration costs over the four-year period ending in 1986. In its staff appraisal of the project, the World Bank indicated that intensive exploration of the area presented significant technical challenges, but that the Krishna-Godavari Basin was the only basin in India with sufficient promise to justify accelerated exploration.

The contractor's findings suggest that the assessment by India and the World Bank of the basin's potential is overly optimistic. Exploration results to date strongly suggest that the basin's highest potential zone is beyond the edge of the continental shelf. Environmental conditions worse than those in the North Sea probably will limit the economic viability of developing future discoveries in this area.

The Krishna-Godavari sedimentary basin covers 14,600 square kilometers on the eastern side of the Indian peninsula. About 60 percent of it is on shore, 30 percent on the continental shelf, and 10 percent in waters exceeding 200 meters in depth. The contractor hypothesized that, although reserves could conceivably be large, much of the oil and gas will be found in small and subtle traps, both structural and stratigraphic.

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In this type of basin, the largest structures are often located in deep water and explored late in the search, if at all. From a simplified structure map presented by ONGC's chief geologist at the Offshore Technology Conference in 1984, the contractor estimated that more than 90 percent of the offshore area lies beyond depths of 200 meters. International oil companies showed no interest in bidding on deepwater tracts in the Krishna-Godavari area during India's second round of lease offerings in August 1982.

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Exploration Results

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Onshore exploration has established the presence of gas, but commercial production has not yet begun. Seismic surveys began in about 1974, and the first well, Narasaput-1, was drilled in 1978. The lack of announcements of commercial discoveries, development plans, or production projections, in the contractor's judgment, means either that drilling continues to be plagued with problems or that a World Bank evaluation of the field's prospects was overly optimistic. The contractor does not believe onshore gas production in the area will achieve more than local significance in the near term because no major markets are nearby.

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Offshore drilling began in 1979. World Bank reporting called the liquid flow rates disappointing and attributed them either to poor reservoir permeability or to formation damage around the well bore. The high gas flow rates in the two zones demonstrate good reservoir permeability for gas. Other exploratory drilling results have been disappointing.

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Economic and Technical Constraints

The Krishna-Godavari area is handicapped by severe weather, strong currents, poor bottom conditions, a steep continental slope, overpressured strata, and small structure sizes. It is subject to severe storms five months out of the year, and four of the seven wells recently drilled in the area were abandoned prematurely because of excessive wave heights or currents. These conditions seriously complicate the design and installation of deepwater production facilities and would probably preclude the use of early production systems, sea-bottom well completions, and other cost-reducing technologies now under development for marginal fields. Exploration efforts thus far indicate that production per well is not sufficient to economically justify offshore platforms.

Potential Reserves

Both onshore gas and offshore oil and gas at Krishna-Godavari are expected to have only negligible impact on Indian energy supplies. The USGS rates the Krishna-Godavari Basin with a "most likely" undiscovered recoverable reserve of 180 million barrels of oil and 0.8 trillion cubic feet of natural gas, based primarily on basin analogies and drilling data. At the 5-percent probability level, the basin was rated with 480 million barrels of oil and nearly 2 trillion cubic feet of gas, about one-fifth that of the Bombay High area. Relatively optimistic USGS estimates reflect ultimate physically recoverable reserves with current technology and do not take into account the adverse environmental conditions in the Krishna-Godavari area. The contractor believes that no economically recoverable hydrocarbons will be produced off shore in the foreseeable future and only negligible amounts will be produced on shore.

Kutch Basin

The Kutch Basin is located on the northwest coast of India, and no economic oil or gas has been found to date. The contractor believes the region is not likely to contribute major additions to India's oil and gas supply.

In addition to surface mapping, other surveys—gravity, magnetic, and seismic—have been conducted, and 11 shallow exploratory holes have been drilled. Two onshore wells were dry, with no shows. An offshore wildcat found oil and gas shows, but it was abandoned. No surface seeps are known; some gas has been reported from shallow water wells. 25X1

Economic and Technical Constraints

The major constraints are the apparent paucity of source beds and a relatively high temperature likely to be encountered in drilling. It appears that the more favorable prospects are at or beyond the continental shelf in deeper water. Terrain features and difficult geologic features make exploration difficult. Amphibious equipment would be required for geophysical and drilling operation because much of the area is low-lying, muddy tidal lagoons and swamps. 25X1

The Resource 25X1

Estimates of potential oil and gas resources in the Kutch Basin must be based on analogies with similar or nearby areas. In 1983, ONGC estimated original oil in place of 4 billion bbl. Applying a recovery factor of 20 to 40 percent to that figure—the range of recovery from most Indian oilfields—potential recoverable reserves would be 800 million to 1.6 billion bbl. 25X1

The USGS has, by extrapolation of Bombay shelf conditions, estimated the "most likely" value for undiscovered recoverable oil at 700 million bbl. Its conservative 95-percent probability estimate is 300 million barrels. USGS estimates of Kutch Basin gas are 4 trillion and 1.8 trillion cf for the same probabilities; these are comparable to Bombay offshore estimates. 25X1

The contractor estimated Kutch potential on the basis of a combination of offshore Bombay and Indus Basin conditions. Although the contractor believes Kutch conditions at this time appear closer to Indus than to Bombay, in the absence of other evidence he estimated 215 million to 290 million bbl of oil reserves in the Kutch Basin. 25X1

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Other Areas

Other areas or basins have been explored only lightly, but the contractor judges that the prospects are slim for significant finds. The USGS estimates that the most likely ultimate oil resources, none of which are proved to date, in these other areas amount to about one-eighth of the country's total. [redacted] 25X1