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The North Caspian Basin: Salvation for Soviet Oil Production?

A Research Paper

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A Research Paper

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The North Caspian Basin: Salvation for Soviet Oil Production?

Summary

Information available as of 15 February 1989 was used in this report.

Moscow needs high levels of oil production to sustain domestic economic growth, earn the hard currency necessary to import vital Western machinery and grain, and prop up economically weak client states. Soviet planners are calling for oil production to stabilize at its present level—just over 12 million barrels per day (b/d)—through the 1990s. Meeting this objective will depend on the development of sufficient new oil resources to offset production declines in existing oil-producing regions. Only one new oil region has this potential—the North Caspian Basin.

We estimate that the North Caspian Basin holds 30-50 billion barrels of recoverable oil. This is equivalent to about half of the initial reserves in West Siberia, the USSR's largest producing region, and roughly three to five times the oil in Prudhoe Bay, Alaska. The North Caspian's Tengiz field alone, which is already under development, may contain as much as 18 billion barrels of recoverable oil.

The North Caspian presents greater challenges to Soviet oilmen than has any other oil region:

- Oil-bearing rocks are about twice as deep as the average in the USSR. [redacted] two to four years have been needed to drill and complete wells at deep fields in the North Caspian. Comparable wells in the United States are completed in less than a year.

- Pressure in the oil reservoirs is three to four times as high as pressures found in West Siberia. As a result, one well at Tengiz blew out of control and burned for about a year until US specialists were called in to control it. Formation temperatures are also high, increasing stress and the likelihood of equipment failures.

- High concentrations of extremely toxic and corrosive gas pose a significant danger to life and the environment

The Soviets, nevertheless, are committed to priority development of the basin. They plan to invest 64 billion rubles in North Caspian petroleum development over the next 20 years—an amount equivalent to 30 percent of oil industry investment over the past 20 years. Demands for development of

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the North Caspian will come on top of resource requirements for established oil regions, where the Soviets are trying to moderate declines in production. The toughest competition for oil industry resources is likely to emerge in the early-to-middle 1990s as the Soviets try to step up investment in West Siberia while building substantial infrastructure in the North Caspian.

The Soviets recognize that they must depend extensively on Western technology and equipment for development of the North Caspian. Moscow has already spent more than $3 billion on Western equipment for the area, and over the next decade—despite tight hard currency reserves—is likely to award additional contracts worth billions of dollars. French and West German firms are likely to get large contracts for expensive oil treatment plants, but US firms will still have promising opportunities to participate as subcontractors in the construction of these plants and to sell oilfield equipment. US oilfield equipment is state of the art and superior to most West European equipment for handling the technical challenges of the North Caspian.

Soviet reliance on the West for technology and equipment to develop the North Caspian is likely to be as large as, or larger than, in any recent project, including the West Siberia–Western Europe gas export pipeline. A cutoff in the supply of Western equipment would stymie petroleum development in the basin. However, the Soviets are likely to be apprehensive about the extent of their reliance on the West. To diminish long-term dependence on outside suppliers, Moscow probably will try to enlist Western firms to upgrade some Soviet oilfield equipment plants and will pursue joint ventures for petroleum equipment more vigorously.

With Western equipment, we estimate that—in the best of circumstances—North Caspian production would grow to about 700,000 b/d in the mid-1990s and to nearly 2 million b/d in the late 1990s. If things go poorly, however, North Caspian production might grow to only 1 million b/d or less by the year 2000. Considering plausible rates of decline in production from existing oil regions, the North Caspian is likely to support national production of roughly 11.5 million b/d in the mid-1990s only in the most favorable circumstances. With poor results in both the North Caspian and existing oil regions, on the other hand, oil production could fall as much as 1.5 million b/d below the 12-million-b/d goal by the mid-1990s.

By the early 1990s, the severity of the shortfall should be apparent. If problems persist in the North Caspian, the Soviets may feel considerable pressure to turn to the West for management and operating expertise. Western management would improve the efficiency and the coordination of different aspects of development; drilling times would be reduced and production would probably increase. Moscow has already approached a Western consortium, which includes a major US oil company, about joint exploration of a field near Tengiz.

We believe, however, that the North Caspian development program would have to fail dismally before the Soviets would seek joint ventures to bring in Western management expertise on a large scale. A joint-venture arrangement probably would concede about half of the oil output to the Western partners. Bringing in Western management to operate more than a few fields in the North Caspian, furthermore, would increase Soviet dependence on the West to new heights, a situation that Moscow probably is anxious to avoid.

If development of the North Caspian moves slowly and the Soviets decide against large-scale Western involvement, they will face the prospect of making do with less oil or pouring even more investment into the oil industry to keep production up. If Moscow decides to maintain oil output at any cost, the drain in investment resources would undermine goals for economic growth and improvement in consumer welfare. On the other hand, keeping oil industry investment constant would cause output to drop sharply and lead to a dramatic reduction in the availability of oil for export.

Contents

Scope Note

This paper analyzes a new oil region—the North Caspian Basin—that the Soviets must develop successfully in the 1990s in order to meet oil production targets. This study builds on earlier projects that analyzed Soviet oil production prospects:

The North Caspian Basin: Salvation for Soviet Oil Production?

Maintaining Oil Production: A Long-Term Soviet Goal

Despite the fact that oil production is becoming increasingly more difficult and expensive to sustain, the Soviet long-term energy program calls for stabilizing production of oil and gas condensate above 12 million barrels per day (b/d) throughout the 1990s (see inset, "Soviet Oil Production in Perspective"). In many ways, Moscow has little choice in the matter:

- Soviet domestic oil consumption is unlikely to fall much—if at all—in the 1990s.[1] Oil provides about one-third of the economy's energy needs and is the source of nearly all motor and aviation fuels.
- Exports of oil to the West earn about one-third of the USSR's hard currency trade revenues, allowing Moscow to make large purchases of grain and high-technology machinery from the West.
- Oil exports to Eastern Europe promote close economic and political ties between Moscow and its CEMA partners. A substantial cutback in deliveries would undermine the fragile economies of Eastern Europe

Table 1
Soviet Oil Production *Million b/d*

	1970	1975	1980	1985	1987	1988
Total	7.06	9.82	12.03	11.9	12.48	12.45
West Siberia	0.63	2.96	6.24	7.32	8.14	8.24
Volga-Urals	4.17	4.52	3.81	2.82	2.60	2.50
North Caspian Basin	0.15	0.15	0.09	0.03	0.08	0.10
Other [a]	2.11	2.19	1.89	1.73	1.66	1.61

[a] Includes production from the Ukraine, Caucasus, Komi ASSR, Central Asia, Azerbaijan SSR, Baltic republics, Georgian SSR, and Kazakhstan SSR.

Maintaining Soviet oil production at current levels through the 1990s without sizable production from a major new oil region would be nearly impossible. All of the major currently producing regions are mature, and output in all of these regions is likely to be declining in the 1990s:

- Production in West Siberia, which accounts for two-thirds of national output, appears to be peaking (see figure 1 and table 1). Because of the continued worsening in quality of new reserves, the Soviets are finding it increasingly difficult to bring on line enough new capacity in West Siberia to offset depletion, let alone provide for growth. We believe that production will most likely continue at roughly 8 million b/d for the next few years and then begin to decline.
- Outside West Siberia, production has been falling since 1976. In the other key producing regions—the Volga-Urals, the North Caucasus, Azerbaijan, and Central Asia—production has been declining for several years. There is little chance that Moscow can reverse these declines. Indeed, Soviet press reports indicate that, at best, Moscow can only hope to stabilize output in many of these regions.[2]

[1] See DI Intelligence Assessment SOV 89-1000 January 1989, *The Soviet Energy Plight: Runaway Investment or Energy Shortfall*

[2] See DI Research Paper SOV 86-1005 November 1986, *Soviet Oil Production Through 1990: Hard Choices Ahead*

Soviet Oil Production in Perspective

The Soviet oil industry has risen to first place in world output by developing a series of oil regions, beginning with hand-dug wells near Baku. Production in each major region has followed a typical cyclical pattern. Oil output initially increases rapidly with the commissioning of high-quality reserves. As the region "matures," production from the old fields declines and production from the new but smaller and less productive fields is unable to offset those declines.[a] Eventually, production from the entire region declines and principal exploration and development moves to a new area.

The Soviets refer to their successive oil regions as a series of "Bakus":

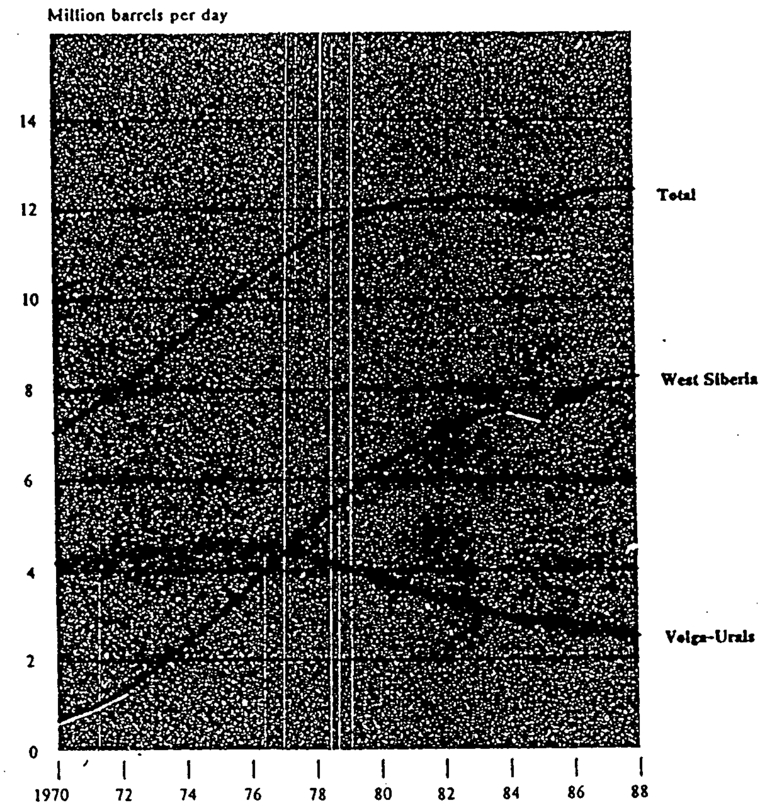
- *The first major oil-producing region, near Baku in the Caucasus, remained the USSR's largest producing region until the early 1950s.*
- *After World War II, the focus of exploration moved to the Volga-Urals region. During the 1950s and 1960s, the development of large, high-quality oilfields in this region allowed national output to grow rapidly. But output from this "second Baku" peaked and began to decline in the mid-1970s.*
- *In the early 1970s, the Soviets moved on to the "third Baku," developing very large, prolific oilfields in West Siberia.*

But during the late 1970s and early 1980s, West Siberian production became increasingly complicated and expensive. Average flows from new wells fell from more than 1,000 b/d in 1975 to 220 b/d in 1985 while investment rose by 75 percent. The share of free-flowing (easy maintenance) wells fell from roughly 85 percent in 1975 to 25 percent in 1985. Also, the average size of new fields fell substantially. Because of these worsening operating conditions, growth in West Siberian output slowed, and national production fell roughly 100,000 b/d and 300,000 b/d, respectively, in 1984 and 1985.

In 1986 the Soviets launched a herculean effort to reverse the decline in oil production. For example, in West Siberia during 1986-90 the Soviets will probably quadruple the number of fields brought on line and double the volume of drilling and new well commissionings over the 1981-85 levels. Because of declining well flows and increasing well depths, the Soviets must increase drilling and new well completions every year to commission enough capacity to offset depletion. Although national output rose in 1986 and 1987, daily production rates leveled off and began to fall in 1988. Because of increasing difficulties in West Siberia, the Soviets must find and develop a "fourth Baku" or risk a sharp fall in oil production

[a] During the early stages of production, reservoir pressures and new well flows are high. Adequate reservoir pressure precludes the need for pumping equipment, simplifying production and maintenance requirements. After several years of production, reservoir pressure decreases, well flows fall, and the volume of water and gas from producing wells increases at the expense of oil. To compensate for falling well flows and rising water cuts, the number of new wells needed to maintain production increases exponentially. The use of expensive and complicated thermal and chemical-enhanced recovery techniques can increase the field's production temporarily, but output eventually plateaus and begins to decline.

Soviet Oil Production, 1970-88



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The Soviets have been actively looking for a major new oil region. For several years they have been exploring and investigating the oil potential of the Barents Sea, other offshore areas, East Siberia, and the North Caspian Basin. All of these areas except the North Caspian offer only limited potential for the 1990s. Severe operating environments, inadequate proved reserves ready for development, and the long leadtimes required for major offshore development will probably preclude any significant production from these regions until at least the late 1990s (see appendix A, "Prospects for Other New Regions").

The North Caspian Basin: Enormous Oil Potential

At about 500,000 square kilometers—larger than California—the North Caspian Basin ranks among the largest sedimentary basins in the world (see figure 2). A Soviet press report indicated that the oil potential of the North Caspian Basin could be equal to the original potential of the Volga-Urals region, which has produced over 40 billion barrels of oil since the 1930s. The Soviets have earmarked development of the North Caspian Basin as the key development effort for the 1990s

US geologists believe that the basin is the world's deepest, with sedimentary rocks almost 25 kilometers—or more than 15 miles—thick at the basin's deepest point. With such a huge volume of rock and a geologic history spanning almost 500 million years, the basin's geology and oil potential present complicated problems. Nevertheless, our analysis of Soviet and Western geological literature indicates that the North Caspian Basin contains the three major factors necessary for the generation and trapping of hydrocarbons:

- *Source rocks* that are typically shales or limestones rich in organic material have been buried for a sufficiently long time and at high enough temperatures to generate oil, condensate, or gas. We believe that at least six separate source rocks in the basin generated hydrocarbons during its geologic history.

- *Subsurface structures* that could act as hydrocarbon reservoirs are abundant. At least nine broad areas of uplift—which contain all of the presently producing fields—are located around the deep central portion of the basin. Within these regions lie numerous arches, domes, and other desirable features that could have trapped upwardly migrating hydrocarbons generated by the source rocks below.

- *Sealing rocks* that are essential to retaining oil in a reservoir are present. A huge salt layer, and the salt domes it creates, offer an excellent sealing mechanism throughout the basin. Other significant seals in the basin are likely to include rocks similar to the reservoir rocks, but with much lower porosity and permeability that would halt further oil movement.[1]

The most important geologic feature in the basin is the thick layer of salt deposited about 250 million years ago. Because salt flows under pressure, it tends to get squeezed into bulb-shaped mounds called salt domes as sediments are laid on top of it. The salt layer horizontally divides the basin, creating essentially two basins in one (see figure 3). In the "above-salt" layers, the numerous salt domes—several hundred have been identified—dominate all other geological features. These salt domes pierce through the sediments in the top half of the basin and have created countless potential traps in the same manner as salt domes in the Gulf of Mexico, the Bay of Campeche, and Iran.

A reconstruction of the basin's geologic history and analysis of the geochemical factors that control oil generation allowed us to arrive at a best estimate of the amount of oil that is trapped in subsurface reservoirs, known as oil in place (see inset, "Estimating a Soviet Basin's Oil Potential," and appendix B). For technical and economic reasons, most of the oil in

[1] Porosity is the percentage of rock volume occupied by open or pore space in which oil can accumulate. Permeability is a measure of the ease with which fluids move through this pore space

Figure 2
North Caspian Basin and Other Major Oil-Producing Regions

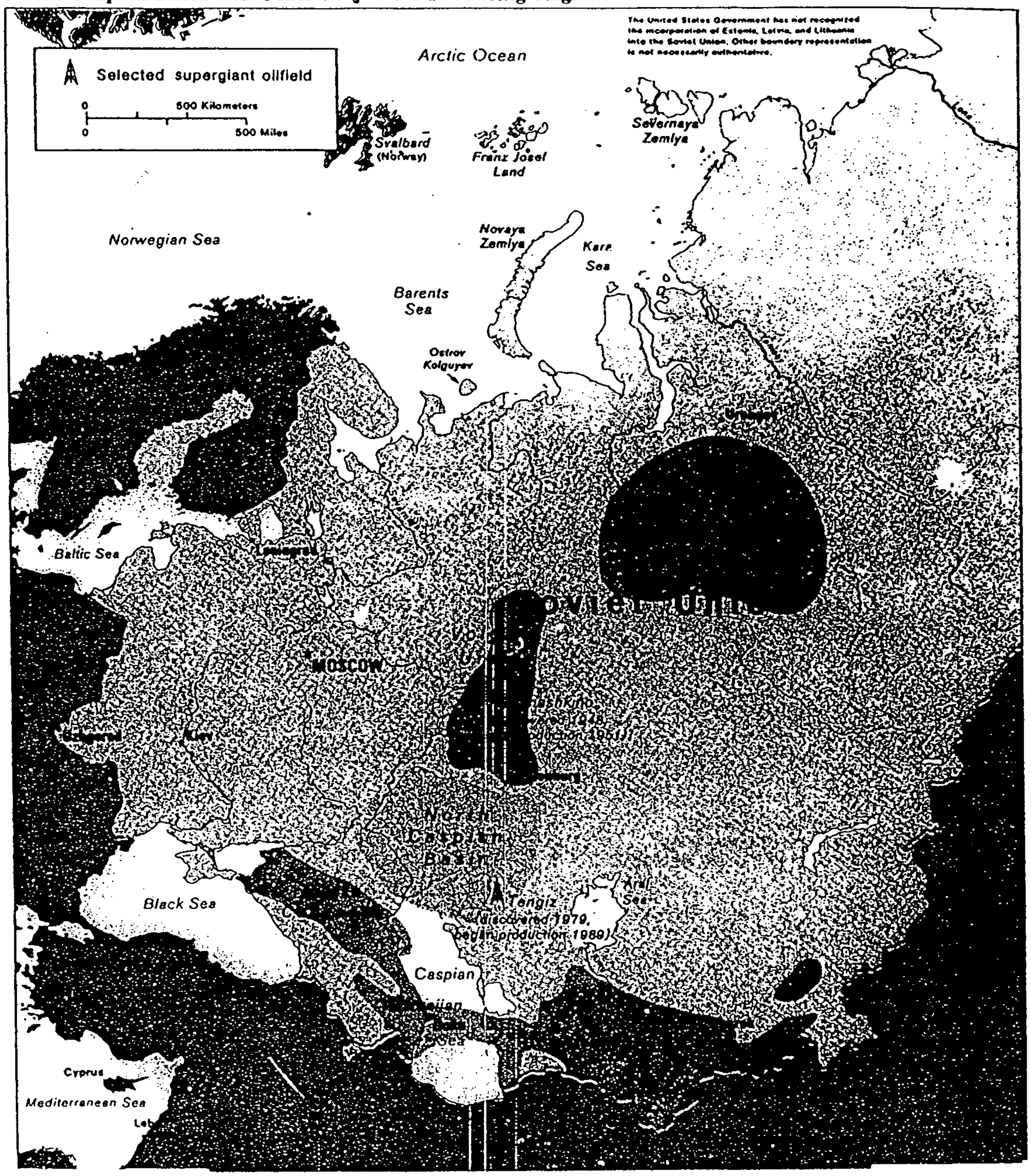
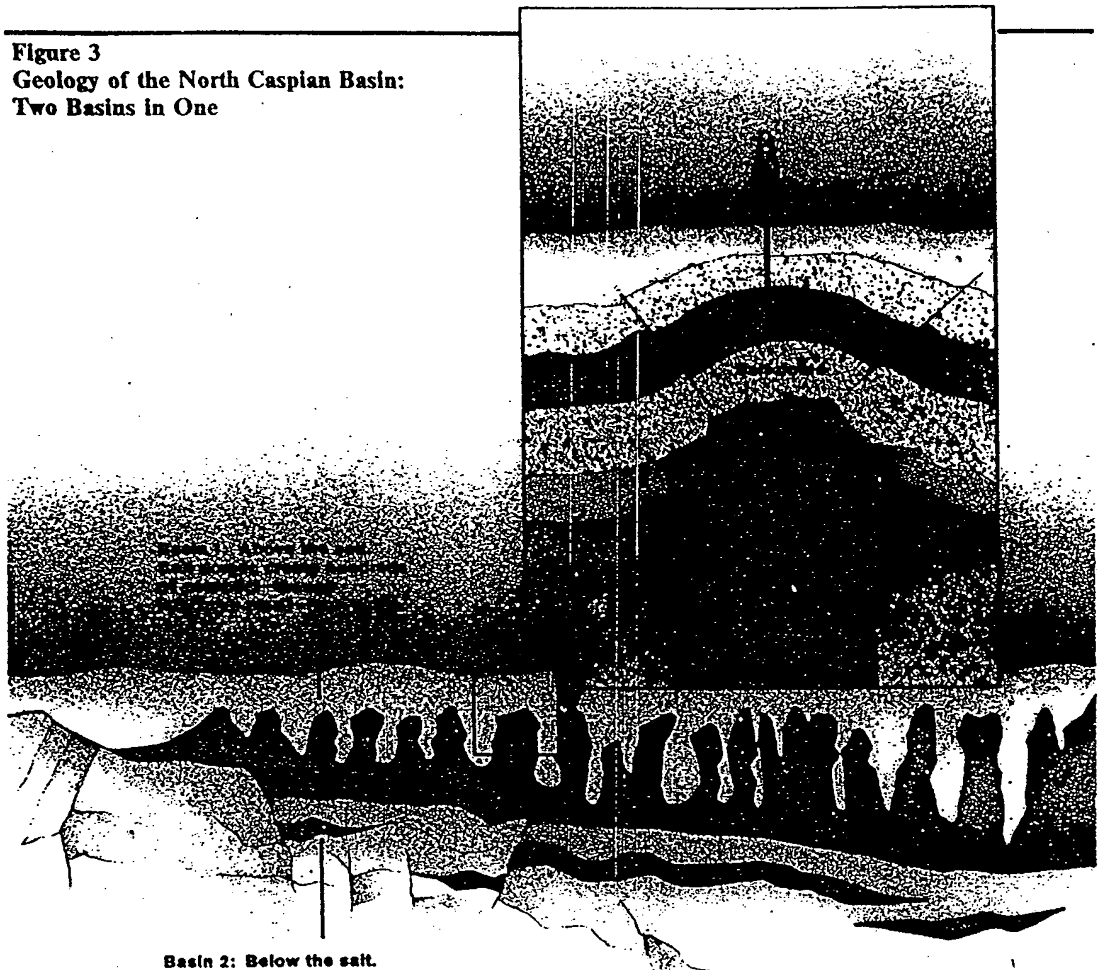


Figure 3
Geology of the North Caspian Basin:
Two Basins in One



Estimating a Soviet Basin's Oil Potential

We begin a geologic analysis by collecting data from a variety of sources, including Western oil industry journals and Soviet open literature. [redacted] *We also analyze* [redacted] *where the Soviets are drilling and, by inference, which areas they believe to be most promising. This analysis, coupled with other sources, provides some information on the depth and extent of the reservoirs and types of fluids being produced. Moreover,* [redacted] *provide quantitative information on many aspects of a field's characteristics.*

For the North Caspian, we tasked [redacted] *to provide a range of estimates of the region's oil potential.* [redacted] *used geochemical analysis to assess the likelihood of oil formation, using information on the extent of organic material in source rocks and temperature profiles. This technique is used by Western industry to provide general guidelines for regions where exploration is still in an early stage.*

We compared and analyzed [redacted] *Soviet data, and reports* [redacted] *While discrepancies remain, most of the information was consistent and mutually corroborating. A general view of the region's oil geology emerged. Our experience has shown that these methods provide a fairly accurate assessment of the magnitude and range of a basin's reserve potential; whether a basin will be oil prone, gas prone, or both; the likelihood for large fields; and whether well flows will be high or low.*

Estimating production, however, is more difficult because we do not know what effort the Soviets will make to get the oil out of the ground. We derived rough projections based on production history in other Soviet oil basins. Finally [redacted] *reviewed the entire project.*

place will never be recovered for commercial use, but the types of reservoirs the Soviets have found to date suggest they can reasonably expect to extract about 20 percent of the oil in place

Our geologic analysis of the North Caspian Basin indicates that recoverable resources could be huge, perhaps rivaling West Siberia in oil potential. Assuming 20 percent of the oil in place can be recovered, we believe that:

- There is an excellent chance that the North Caspian Basin holds nearly 30 billion barrels of recoverable oil, or roughly three times as much oil as Prudhoe Bay.
- The basin has a fair chance of yielding about 48 billion barrels of oil, an amount roughly equal to initial reserves of the Volga-Urals region.
- At the extreme, the ultimate recovery could exceed 80 billion barrels, more than three times current proved reserves in the United States (see table 2).

We estimate that about one-fourth of the recoverable oil will be found in the shallow fields above the massive salt layer. The Soviets have already developed 70 above-salt fields that presented few technical challenges.[4] New above-salt reservoirs are likely to be found in structures associated with the numerous salt domes scattered throughout the basin, although reservoirs near the center of the basin are more likely to yield gas than oil. These potential above-salt oilfields,

[4] The first above-salt fields were developed more than 50 years ago in the Emba region on the northeast shore of the Caspian Sea. Production from these fields has been declining since the mid-1970s, when output reached roughly 50,000 b/d

Table 2
Estimated Recoverable Oil in the North Caspian Basin

Billion barrels

	High Level of Confidence	Medium Level of Confidence	Low Level of Confidence
Total	**29.4**	**47.6**	**81.6**
Above the salt	7.1	11.5	19.7
Below the salt	22.3	36.1	61.9

though numerous, will be smaller and geologically more complex than those already discovered. Furthermore, as is the case with existing fields, well flows will be low because they are likely to contain heavier, more viscous oil.

The remaining three-fourths of the recoverable oil in the North Caspian Basin is likely to lie below the salt layer at enormous depths—about 4,500 meters and deeper. Reservoirs in the "below-salt" section are formed by different geological mechanisms and could be of substantial size. We believe the geographic location of potential below-salt reservoirs may be limited to a ring around the perimeter of the basin where subsurface rock types are conducive to large accumulations of oil (see figure 4).

So far, the Soviets have discovered 15 oilfields below the salt layer. A number of deposits, including the supergiant Tengiz oilfield, are currently under development.[5] A comparison with analogous basins elsewhere and analysis of Soviet geological data suggest that the Tengiz field, which probably contains about 18 billion barrels of recoverable oil, is likely to be the largest, or one of the largest, fields in the basin and will account for at least two-thirds of North Caspian production in the 1990s. (Appendix C examines Tengiz in more detail.) But we cannot rule out the possibility of other multibillion-barrel oilfields in the North Caspian Basin. The deep below-salt rocks offer excellent possibilities for the discovery of additional major fields.

[5] Oilfields with recoverable reserves greater than 500 million barrels are considered giants. To rank as a supergiant, a field must contain recoverable reserves of at least 5 billion barrels

While we consider the oil at Tengiz to be available for development, most of the rest of the potentially recoverable oil in our estimate has yet to be discovered. Only a deliberate program of exploratory and development drilling can convert oil in place into proved reserves. Until such a program is successful, most of the other oil in the North Caspian Basin can only be considered a potential resource. While our analysis confirms recent Soviet claims that the North Caspian Basin could become a major oil-producing region in the future, the timing of production is problematic.

Developing Below-Salt Deposits: Technical Challenges

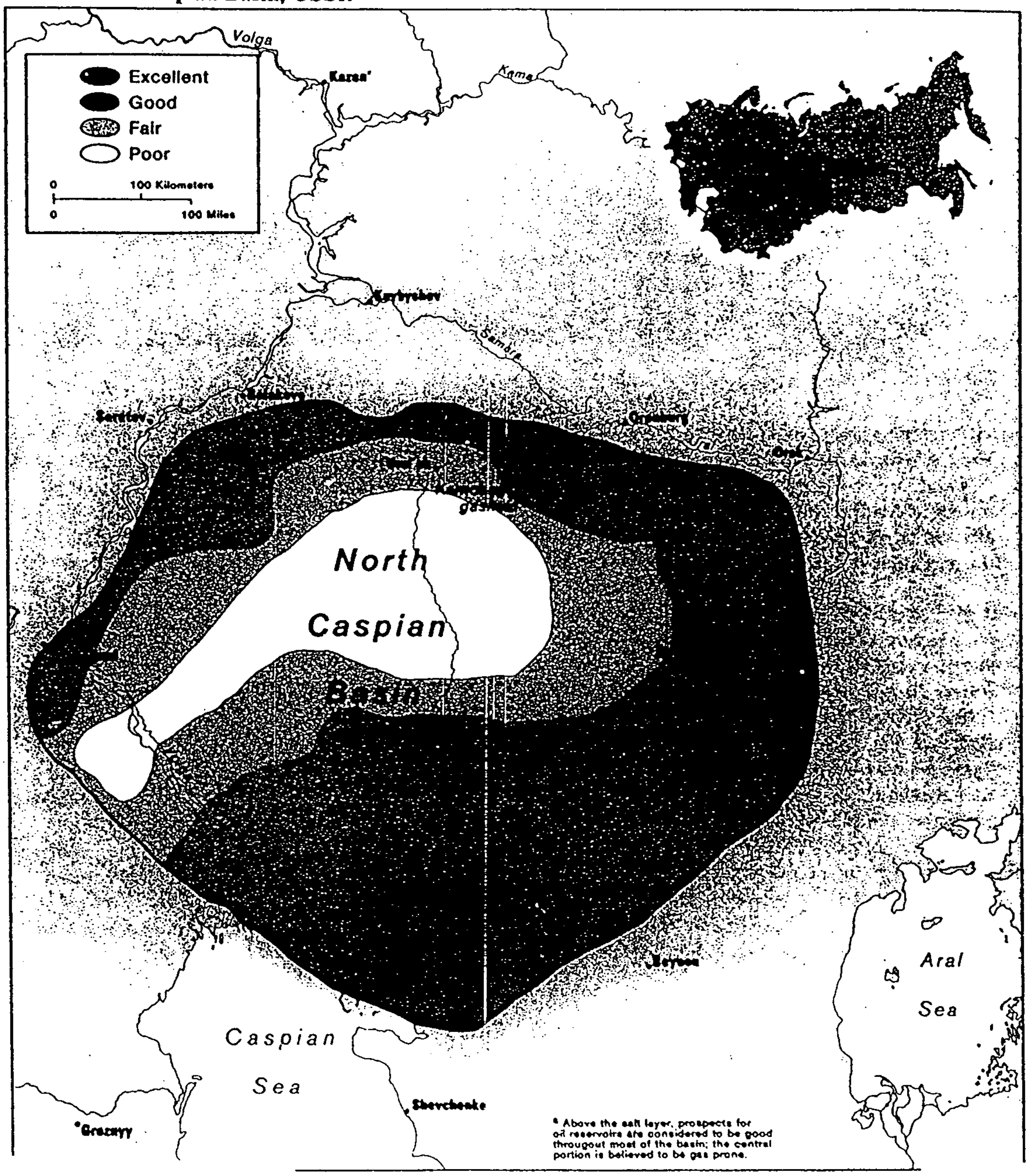
Soviet geologists have characterized the below-salt deposits in the North Caspian Basin as the USSR's most difficult deposits. Efforts to date to develop the region's deep oil potential show that the Soviets are having great difficulty dealing with major technical problems and that Western technology is critical to solving them. Development of fields in the North Caspian has been complicated, expensive, and slow because:

- Depth to oil-bearing rocks is about twice as deep as average drilling depths in the USSR. Soviet drilling crews lack the expertise and much of the appropriate equipment and technology to drill deep wells efficiently. For example, we estimate that, on average, two to four years have been needed to drill and complete wells at Tengiz (see appendix D). A recent Soviet press report indicated that annual drilling plans at Tengiz would be completed in a month elsewhere in the USSR. Drilling crews, nonetheless, often fail to meet plan, and some managers of drilling crews reportedly have been fired for incompetence.

- Pressure in the oil reservoirs is three to four times as high as pressures found in West Siberia. Drilling crews must use special equipment and undertake precautions to avoid blowouts.[6] The most visible sign

[6] A blowout is an uncontrolled flow of oil and gas that can occur during drilling operations when the downhole pressure of the drilling fluid is less than the upward pressure of oil and gas trying to escape the rock formation.

Figure 4
Prospects for Major Oil Reservoirs Below the Salt Layer in the North Caspian Basin, USSR[a]



[a] Above the salt layer, prospects for oil reservoirs are considered to be good througout most of the basin; the central portion is believed to be gas prone.

Figure 5. Oil well at Tengiz burning out of control. The blowout occurred because of both human error and equipment malfunction. The Soviets tried for a year to shut down the well but, because of their lack of specialized equipment and experience in controlling major blowouts, were unsuccessful. US and Dutch specialists were brought in and brought the blowout under control within a few weeks.

of Soviet inability to handle high reservoir pressures was the well that blew out of control in June 1985 at Tengiz (see figure 5). The Soviets narrowly missed another blowout in 1988, and oil ministry officials reportedly remain very concerned about the potential for future blowouts.

- High concentrations of extremely toxic and corrosive gas pose a significant danger to life and the environment. The Soviets need special plants to process oil with high concentrations of deadly hydrogen sulfide. Technical journals indicate that, at some locations and depths, Tengiz oil contains little, if any, hydrogen sulfide, but most reporting indicates that the presence of hydrogen sulfide is the rule rather than the exception.'

- Formation temperatures are high, increasing stress and the likelihood of equipment failures. High temperatures act in conjunction with the hydrogen sulfide to accelerate corrosion (see table 3).

Because of these technical challenges, development of Tengiz has been much slower than that of the USSR's other very large oilfields. Romashkino in the Volga-Urals region, discovered in 1948, began production in 1951. Samotlor in West Siberia, discovered in 1965, began production in 1969. In contrast, Tengiz, discovered in 1979, did not begin production until 1989.

' The level of hydrogen sulfide can vary depending on the extent of sulfur impurities present at specific locations during the oil-formation process

Finding the Resources and Technology

Burgeoning Requirements

Because of its technical challenges, the North Caspian Basin will be relatively expensive to develop. The Soviets plan to invest 64 billion rubles in North Caspian petroleum development over the next 20 years—an amount equivalent to 30 percent of oil industry investment over the past 20 years. Some of these funds are almost certainly earmarked for domestic oilfield equipment, which the Soviets will need in substantial quantities to meet production targets. Even without the demands of the North Caspian, however, oilfield equipment plants are working above their design capacity. Shortages of such equipment will force new investment in this industry or more imports of equipment.

The North Caspian also needs substantial investment in housing, roads, and other infrastructure, although not as much as would be required for a remote, undeveloped area such as West Siberia. The North Caspian region already has a railroad, hard-surface

Table 3
Characteristics of Key Fields in the North Caspian Basin

	Depth (*meters*)	Formation Pressure (*pounds per square inch*)	Temperature (*degrees Centigrade*)	Volume of Hydrogen Sulfide (*percent*)	Volume of Carbon Dioxide (*percent*)
Tengiz	4,000-6,500	6,500-13,000	Up to 150	20-25	3-5
Astrakhan'	4,100	10,000	About 105	25	14-24
Karachaganak	4,300-5,300	6,700-8,500	Up to 95	5	5

roads, many large cities, and two crude oil pipelines that are currently operating at less than full capacity. Moreover, the North Caspian is near the industrial regions of the USSR and the Volga-Urals region where many oilfield equipment plants and petroleum refineries are located.

In addition to investment funds, the Soviets must supply the North Caspian Basin with trained oilfield personnel, presently in short supply. Some drilling crews are being flown in to the basin on temporary assignment while others are being permanently reassigned. The Soviets are also relying in part on East European workers at Tengiz, and may put pressure on Eastern Europe to supply greater numbers. The East Europeans have little interest in doing this, but would probably concede because of their heavy reliance on energy supplies from the USSR

Demands of the North Caspian will come on top of resource requirements in existing oil regions, where the Soviets are trying to moderate declines in production. If Moscow transfers resources from the older regions to support development in the North Caspian, output probably will decline faster in the older regions. In at least one case, reassignment of workers from an older field to Tengiz reportedly caused production to decline in the older field. West Siberia, in particular, has acute shortages of infrastructure and will fall further behind if the lion's share of available resources is allocated to the North Caspian.

The most difficult period for Moscow to balance these competing demands will be the early-to-middle 1990s, when the oil industry will be stepping up investment in West Siberia while building substantial infrastructure in the North Caspian. The Soviets perceive an urgent need to maintain oil production but will be hard pressed to find sufficient resources to support both projects. If the Soviets allocate whatever investment is necessary for both, we estimate that oil industry investment would rise dramatically—at least on the order of 15 percent per year through the mid-1990s, compared with annual growth of about 10 percent during 1981-87. By the mid-1990s, annual oil industry investment could be as much as 35 billion rubles, compared with roughly 15 billion rubles in 1987. The share of oil industry investment in total investment would almost certainly rise from its current level of about 7.5 percent.

The Soviets have few prospects for shifting resources from other energy sectors to oil development:

- Maintaining growth in natural gas supplies is requiring increasing investment for gas pipeline construction, for gas storage facilities, and for converting consumers from oil to gas.
- Increasing electricity supplies by utilizing coal reserves in the eastern USSR will require sizable investment to develop and implement technology for using low-quality coal and transmitting power over long distances.

- Getting the nuclear program back on track in the wake of the Chernobyl' accident is requiring, among other things, increased spending to improve safety.

In the past, when investment requirements for the oil industry have risen sharply, the Soviets have held back on investment in the coal industry. Even if the Soviets decided to cut coal investment substantially, the amounts made available would be much too small to cover a doubling of oil industry investment.

Acquiring the necessary resources from other sectors of the economy is equally problematic. Gorbachev's top priority projects—industrial modernization and improving consumer goods industries—have very large investment requirements. Ultimately, the Soviets will have to choose between maintaining oil production and keeping commitments to modernization and to the consumer.

Western Equipment and Technology: Essential Ingredients

Much of available Soviet equipment and technology for extracting and processing oil and gas is inadequate for the great depths, high pressures, and extremely corrosive conditions of the North Caspian Basin. During the early 1980s, for example, drilling operations at Astrakhan' reportedly were often delayed because domestic drill-pipe and well casing was not sufficiently corrosion resistant and leaked frequently. Soviet-made wellheads and blowout preventers have also proved inadequate.[8] According to a 1987 press report, a "specially designed" wellhead manufactured by a Baku oilfield equipment plant failed in "measurable hours" due to corrosion. Even the best blowout preventers in Eastern Europe, furthermore, would not be adequate and would probably lead to numerous blowouts, lost wells, and perhaps even fatalities. The Soviets have also had great difficulty fabricating and installing equipment in the processing plants needed to remove high concentrations of hydrogen sulfide from North Caspian oil and gas.[9]

As a result of these problems, Moscow has spent more than $3 billion for the North Caspian fields over the last three years on Western equipment for drilling, producing, and processing operations. The Soviets turned to Western suppliers for high-strength, corrosion-resistant drill-pipe and well casing.[10] Furthermore, the USSR has imported from the United Kingdom and West Germany nearly all of the corrosion-resistant, high-capacity wellheads used at Astrakhan' and Tengiz.[11] In addition, the Soviets have imported a large number of highly rated (10,000 pounds per square inch and greater) blowout preventers.

The USSR has relied exclusively on Western firms to build pipeline gathering systems:

-

[8] A blowout preventer, which is used to control well pressure, is an assembly of heavy-duty valves that can be closed rapidly

[9] Before 1980, the USSR had only two plants capable of processing sour gas, one at Mubarek in Central Asia and the second at Orenburg. The plant at Mubarek was built in the late 1960s using relatively old Soviet technology capable of handling only low levels of hydrogen sulfide (less than 10 percent). In addition, the Soviet press reports that initial startup operations were beset by problems. At Orenburg, the Soviets opted to purchase the sour gas plant from the French engineering firm Technip, probably because of earlier problems at Mubarek, the need to process larger volumes of gas with higher concentrations of hydrogen sulfide at Orenburg, and a lack of confidence in Soviet technology.

[10] Despite repeated inquiries, the USSR has so far purchased only a few deep-drilling rigs from Western firms. Most of the deep rigs imported over the past 10 years have come from Romania and are reportedly capable of drilling to 8,000 meters. The Soviets, however, have recently expressed dissatisfaction with the Romanian rigs. In October they approached Western firms about the prospect of a joint venture to manufacture deep-drilling rigs. In addition, the Soviets are purchasing Western workover rigs (rigs used to pull tubing and conduct well maintenance) capable of working to 6,200-meter depths for use in the North Caspian Basin

[11] The Soviets have also purchased a large volume of well-completion equipment for Tengiz and Astrakhan'. These purchases include downhole equipment used to perforate well casing; equipment to seal off the producing formation; downhole monitoring equipment; and valve assemblies to control production from the surface.

Table 4
Western Petroleum Treatment Plants in the North Caspian Basin

	Built by	Cost (*million US $*)	Daily Output	Status
Karachaganak	Gastechnik (West Germany) [a]	45	Separation of gas and liquids	Operating
Astrakhan' Phase I [b]	Technip (France)	395	8.2 million cubic meters (m^3) natural gas; 40,000 barrels condensate liquids; 8,200 tons sulfur	Operating at less than design capacity
Astrakhan' Phase II [b]	Technip (France)	250	8.2 million m^3 natural gas; 40,000 barrels condensate liquids; 8,200 tons sulfur	Under construction
Tengiz, Phase I	Lurgi (West Germany) and Litwin (France)	200	4.1 million m^3 natural gas; 60,000 barrels oil; 2,700 tons sulfur	Nearing completion
Tengiz Phases II and III	Lurgi (West Germany) and Litwin (France)	300	8.2 million m^3 natural gas; 120,000 barrels oil; 2,700 tons sulfur	In early stage of construction

[a] Additional processing is done at Orenburg.
[b] Analysis of overhead imagery indicates that, at Astrakhan', the catalytic reforming and diesel fuel hydrotreating units are of Soviet design.

Under these contracts, the Soviets receive well-site test separators, central gathering stations, gathering lines linking the wells, larger lines linking central gathering stations to the processing plants, and communication systems that monitor and control the entire network.

The Soviets have also relied exclusively on Western firms to build oil- and gas-processing plants (see table 4). After purchasing the first Tengiz plant the Soviets indicated they would construct subsequent plants themselves, but they eventually turned to Western suppliers. During initial negotiations for the second treatment plant at Tengiz, Soviet negotiators began by insisting on using as much Soviet equipment as possible. As the negotiations progressed, the Soviets requested Western contractors to supply more and more of the processing equipment.

The Soviets, however, appear to be experiencing problems in operating the plants built by Western firms. Although the Soviet press reported that the gas treatment plant at Astrakhan' was completed in 1987, other press reports allude to operating problems and frequent shutdowns. only part of the facility is operating. Despite the use of Western equipment, lax safety standards have continued to plague the project. An explosion in March 1987 at an underground gas condensate storage facility, for example, killed four people and resulted in a temporary shutdown of the gas-processing plant.

The Soviets will have to continue these imports, creating substantial trade opportunities for the West over the next decade. There are few firms outside of Western Europe and North America that can supply the equipment the Soviets need to develop the North Caspian. Over the next decade, the Soviets are likely to award contracts worth billions of dollars.

[redacted]

Moscow probably will continue to award most of the large contracts for oil treatment facilities to French and West German firms, but US firms will still have opportunities to participate as subcontractors in the construction of these plants. The Soviets see several advantages to dealing with West European suppliers. First, firms from France and West Germany are already on site and are building a number of oil and gas treatment plants. The Soviets have awarded them subsequent contracts for additional treatment plants. The Soviets may want to continue dealing with these firms to facilitate assimilation of this technology.

[redacted]

Furthermore, the Soviets appear to see little threat of equipment embargoes from West European firms. With thousands of West European jobs dependent on Soviet orders, Moscow may hope that West European governments will be reluctant to agree to US policy initiatives that run counter to Soviet interests.[11] The Soviets may perceive, moreover, that West European suppliers get comparatively fast approval for export licenses. ~~According to~~ [redacted] the Soviets told [redacted] they purchased some geophysical equipment in 1987 from a French firm because the French were able to obtain export guarantees on all of the computer equipment

North Caspian Production Prospects

We estimate that, in the most favorable circumstances, the North Caspian Basin could produce as much as 700,000 b/d in the mid-1990s and about 2 million b/d in the late 1990s (see inset, "Estimating Oil Production in the North Caspian"). Over the next decade, most of North Caspian oil production is likely to come from Tengiz. Given the very slow pace of exploratory drilling, the discovery and delineation of other large fields will require several years. (The Soviet press reports that Tengiz itself will not be completely delineated until the early-to-middle 1990s).

Given this production outlook for the North Caspian Basin, the Soviets would need production from existing oil regions of about 11.5 million b/d in the mid-1990s and 10 million b/d in the late 1990s to meet their production goal of 12 million b/d over the next decade. In our best case scenario, we assume the Soviets are successful in efforts to moderate the

[11] For some of these West European countries, petroleum-related goods and services may become the single-largest export item. For example, exports of steel pipe and petroleum equipment accounted for roughly 35 percent of the value of French exports to the USSR in 1987, compared with 23 percent in 1986 and 16 percent in 1985

Estimating Oil Production in the North Caspian

Our first key assumption in deriving best case estimates is that production trends in the North Caspian Basin over the next 10 years will be similar to production trends in the Volga-Urals and West Siberia during their first 10 years of production. These three oil regions have in common key factors that determine oil production:

- *The amounts of potentially recoverable oil are very large. Our medium level of confidence estimate of about 48 billion barrels for the North Caspian is close to the initial Volga-Urals reserves of about 50 billion barrels.*

- *A substantial share of the basin's recoverable oil is located in one oilfield. Tengiz, with 35 to 40 percent of our estimate, is similar in importance to Romashkino and Samotlor.[a]*

- *Domestic priority for development is high. The Soviet press has repeatedly indicated that development of the oil resources of the North Caspian is vital to the economy. The Volga-Urals and West Siberian regions received similar priority during their first 10 years of production.*

For our best case scenario, therefore, we assume that the North Caspian will be producing in the late 1990s about the same share (1.5 percent) of the basin's recoverable oil (48 billion barrels) as was produced in the Volga-Urals and West Siberia 10 years after production began:

	Resource Base (*billion barrels*)	Annual Production 10 Years After Start (*million barrels*)	Ratio[a] (*percent*)
Volga-Urals[b]	50-55	766 (*2.1 per day*)	1.5
West Siberia	70-80	1,100 (*3 per day*)	1.5
North Caspian Basin	48	720 (*about 2 per day*)	1.5

[a] Ratio of annual production 10 years after production began to estimated recoverable reserves for the basin.
[b] For the Volga-Urals region, we assumed an initial development date of 1950. Although some development work was undertaken during 1945-50, little was accomplished because of the effects of World War II.

Although well flows, especially at Tengiz, are likely to be higher than in the other regions because of high permeabilities and high formation pressures, we are assuming that this plus will be offset by slow drilling and the need to build oil treatment plants.

Even so, our estimates assume that the Soviets will improve their ability to cope with the technical challenges of the North Caspian and reduce the three to four years now needed to drill and complete wells to one and a half to two years. We believe that this would be difficult but not impossible, as even these reduced drilling times would still be very long by Western standards.

Finally, we assume that the Soviets will add oil-processing capacity fast enough to keep pace with oilfield development. In recent negotiations for the Tengiz II and Tengiz III plants, the Soviets have

[a] For the Volga-Urals region, Romashkino was the key field with about 12-15 billion barrels of recoverable reserves, about 25 to 30 percent of the basin's total. In West Siberia, Samotlor, with 20 billion barrels, was the major discovery with about 25 percent of the basins' estimated reserves.

reportedly expressed more concern about accelerating the timetable for bringing these plants on line. Soviet negotiators reportedly want these plants operating within 30 months of contract signing, compared with the 48 months that will be needed to build the first plant. [redacted] *do not believe this timetable can be met. According to* [redacted] *about 14 to 16 months are needed just to order, manufacture, and receive some of the equipment, such as compressors and rotating equipment.*

If, on the other hand, the Soviets fail to shorten drilling times and/or encounter serious difficulties with oil-processing capacity, we estimate that production in the late 1990s from the North Caspian could be as little as half of the best case levels.[b]

To estimate production from the North Caspian in the mid-1990s, we again relied on production history in the Volga-Urals and West Siberian basins. Our analysis shows that 60 to 65 percent of the growth in output during the first 10 years of development occurred in the latter five years. The initial period is used to build social, transport, electrical transmission, and production infrastructure. At the onset of development, production usually lags until construction of some of this infrastructure is completed. Given our production projection of 2 million b/d in the late 1990s, we estimate that North Caspian output could approximate 700,000 b/d in the mid-1990s

[b] *There are no appropriate analogies nor is there enough production history at Tengiz to make reliable worst case estimates. Our estimate merely assumes that the Soviets continue to complete wells at the present rate and that each completed well yields 5,000 b/d, which is comparable to well flows in analagous basins in the Gulf of Mexico*

decline in West Siberian output and devote whatever investment is needed but that no significant discoveries are made in existing regions (see inset, "Projecting Oil Production in Existing Regions"). In this case, production in oil regions other than the North Caspian could fall to roughly 11 million b/d in 1995 and to 10 million b/d in the late 1990s. Under our worst case assumptions, production falters badly in West Siberia and oil production from existing regions is about 10 million b/d in the mid-1990s and almost 8.5 million b/d in the late 1990s:

	Million b/d				
	1990	Mid-1990s		Late 1990s	
		Worst Case	Best Case	Worst Case	Best Case
Total	**12.1**	**10.3**	**11.6**	**9.3**	**12.0**
North Caspian Basin	0.15	0.4	0.7	1.0	2.0
West Siberia	8.0	6.5	7.2	5.3	6.5
Other	3.95	3.4	3.7	3.0	3.5

Thus, to keep output close to 12 million b/d in the 1990s, the Soviets would have to both successfully develop the North Caspian and moderate declines in production in existing regions, especially in West Siberia. To meet production goals, output in all of these regions would have to be at the high end of our estimated ranges. Even in our best case production scenario, the Soviets probably will have to cope with at least a slight decline in production during the mid-1990s as production drops in other regions and North Caspian production is still in initial stages (see figure 7). Poor results in both the North Caspian and West Siberia would mean a sharp decline in oil output in the 1990s

Projecting Oil Production in Existing Regions

Best Case Assumptions
For this scenario we assume that West Siberian output peaks then declines slowly in the 1990s at an average annual rate of 2 percent—about half the rate observed in the Volga-Urals region after output peaked there. Nearly everthing goes well in West Siberia: production from older fields declines slowly while new fields are better than anticipated; sufficient infrastructure and personnel are available to service and repair an enormous inventory of older wells; and transportation bottlenecks to developing an escalating number of fields are ameliorated.

In addition, the Soviets are successful in their efforts to stabilize the production decline in other regions. Output in the 1990s declines at an average annual rate of about 1.5 percent, compared with the observed 4.5-percent annual decline during 1981-85 and the projected 2.8-percent annual decline during 1986-90.

We further assume that the Soviets increase oil industry investment to whatever level is necessary to carry out this program.

Worst Case Assumptions
In our worst case scenario, West Siberia output falls at the same rate as it did in the Volga-Urals.[a] We assume that the quality of new fields—in terms of size and well flows—continues to worsen; production from fields commissioned in the mid-to-late 1970s falls sharply in the 1990s, at the rate observed at Samotlor after 1980; transport bottlenecks and equipment shortages hamstring Soviet efforts to develop new fields and keep a high share of the well inventory properly maintained and operating; and the frequency of ruptures and the need to replace interfield gathering pipelines increases, halting production temporarily at some fields.

In addition, the Soviets are unsuccessful in further slowing the decline in output from other regions. Output in these areas continues to decline at the rate observed in the mid-to-late 1980s, about 2.8 percent.

We also assume that growth in oil industry investment stays at or near current levels.

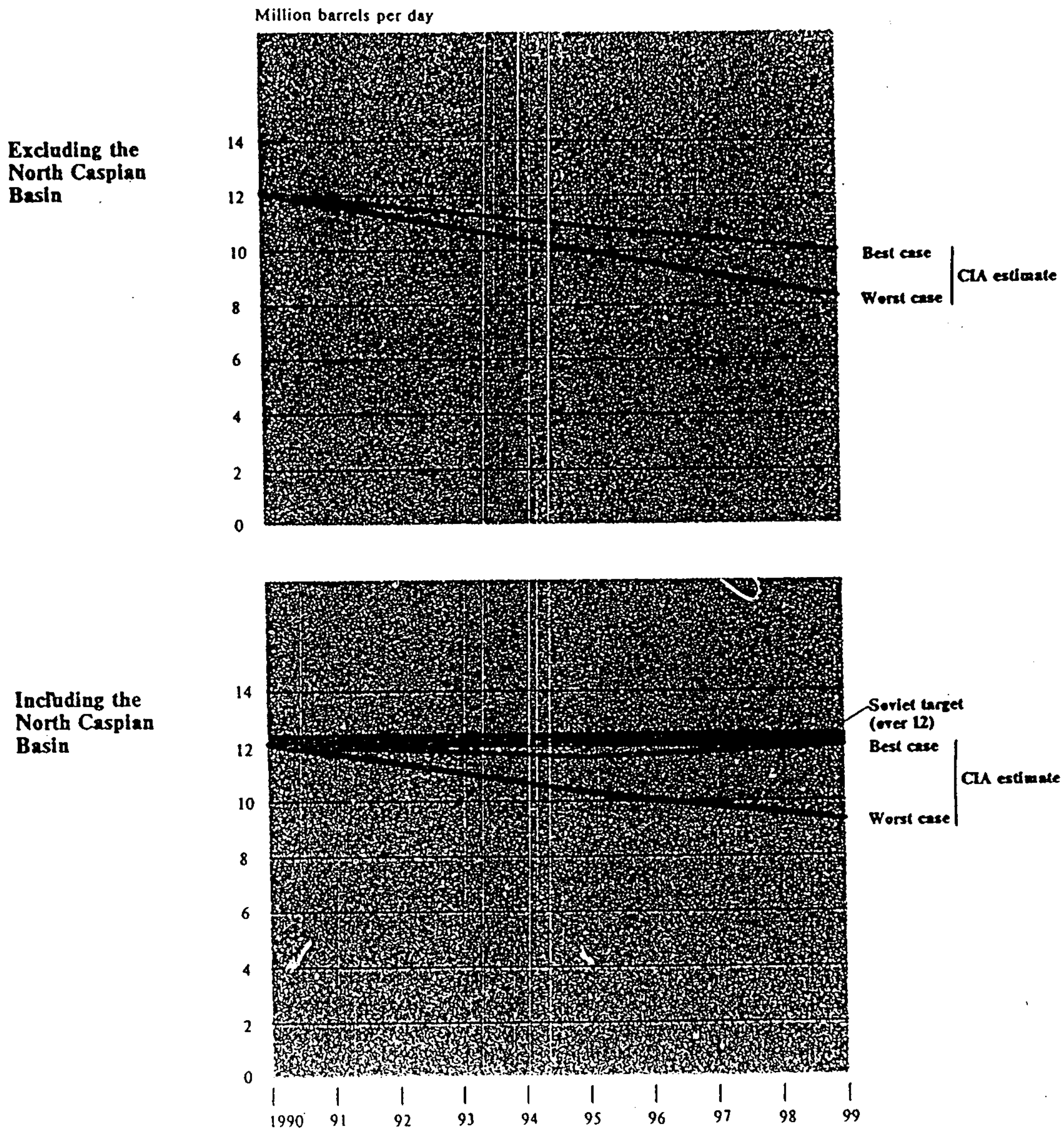
[a] Because the Soviets developed the middle Ob' fields in West Siberia at a faster rate and in a more haphazard manner than those in the Volga-Urals region, West Siberian output could decline at a faster rate than Volga-Urals production

While we cannot rule out the possibility of a major discovery in existing regions that would substantially improve production prospects, we believe it is unlikely over the next several years. Nevertheless, West Siberia is a large region, and exploration is not complete. In their efforts to maintain oil production in this region, the Soviets will move exploration northward, but the trend toward smaller and less productive fields is likely to continue

Implications

Soviet oil production in the 1990s will be well short of plan targets unless the program to develop the North Caspian Basin succeeds. If output from existing oil regions falls sharply over the next decade, production from the North Caspian will have to rise rapidly to keep Soviet oil output from sinking to a level that

Figure 7
Soviet Oil Production Prospects, 1990-99



would undermine domestic economic growth or virtually preclude exports by the late 1990s. Curtailing exports, in turn, ultimately would mean a severe reduction in the hard currency earnings needed to sustain imports of Western grain and machinery and would risk devastating the already fragile economies of Eastern Europe.

Western equipment and technology have already proved vital in developing North Caspian oil resources and will continue to be essential in the 1990s. The Soviets have few prospects for modernizing and expanding their oil equipment industry rapidly enough to meet the demands of the North Caspian in the next decade. The industry historically has been slow to develop new equipment and make quality improvements.[14] To fill requirements of the North Caspian, Moscow would have to design, develop, and test a broad range of advanced, corrosion-resistant equipment of high quality and precision with sophisticated control systems. Given the current state of Soviet manufacturing technology, such an effort would probably require a number of years.

A cutoff in the supply of Western equipment would stymie development of the region's oil potential. The Soviets would eventually make gains in manufacturing the needed equipment, but this would probably require a major shift of resources from other sectors of the economy. In the interim, oil wells would take much longer to drill and complete and the likelihood of blowouts would increase. Moreover, the use of Soviet processing technology in lieu of Western oil treatment plants would substantially slow the addition of processing capacity and increase the risk of leaks of toxic gases and fatalities. Growth in production would have to be slowed to match available processing capacity.

Even with Western equipment and technology, the Soviets probably will find it difficult to achieve quick gains in production from the North Caspian. Our best case production estimate for the North Caspian assumes substantial reduction in the time needed for drilling oil wells and building oil treatment plants. So far, however, continued difficulty in drilling deep wells and building the processing plants suggest that the Soviets could face substantial delays in developing the North Caspian's oil resources. Drilling oil wells, building the gathering pipeline network, and adding oil treatment plants must be well planned and synchronized. Delays in any of these aspects of development would hold back growth in oil production.

By the early 1990s, it should become clear how successful Soviet development of the North Caspian is likely to be. Current contracts for oil treatment plants imply a production target of about 200,000 b/d from Tengiz alone by 1991-92. If the Soviets fail to achieve this production target and realize that they are facing a worst case production scenario for the 1990s, they may feel considerable pressure to seek joint ventures with the West to obtain management and operating expertise.

North Caspian development would be an ideal candidate for joint ventures because its product could be readily sold for hard currency. Furthermore, there are many Western firms, particularly in the United States, with experience in dealing with the kinds of technical challenges found in the North Caspian Basin. Indeed, Moscow has already approached a Western consortium, which includes a major US oil company, about joint exploration of a field near Tengiz. If a deal is finalized, the US company reportedly would be allowed to export oil from the USSR in order to create a hard currency fund from which consortium members would be allowed to repatriate profits.

Western management would certainly improve efficiency and reduce operating costs. In addition, the coordination of different aspects of development would improve; drilling times would be reduced and

[14] For example, the Soviets took five years to develop and produce standard gas-lift equipment that was urgently needed in West Siberia. The petroleum machine-building ministry was frequently criticized for this delay

production would probably increase. We believe, however, that the North Caspian development program would have to fail dismally before the Soviets would be willing to bring in Western management expertise on a large scale:

- A joint-venture arrangement probably would concede about half of the oil output to the Western partners. For the Soviets to perceive this arrangement as advantageous, they would have to believe that production would more than double.

- Bringing in Western management to operate more than a few fields in the North Caspian would increase Soviet dependence on the West to new heights, a situation that Moscow probably is anxious to avoid. To minimize economic vulnerability, the Soviets would almost certainly want strong guarantees against equipment embargoes.

If North Caspian development moves slowly and the Soviets decide against large-scale Western involvement, they will face the prospect of either making do with less oil or directing enough investment into the oil industry to keep production up. Programs now under way to modernize oil refineries, increase substitution of gas for oil, and wean client states from Soviet oil exports would, if successful, make small declines in oil output less disruptive. Prospects are poor, however, for implementing conservation programs in the 1990s that would substantially reduce the economy's oil requirements. Thus, if large declines in oil output were to occur over the next decade, they would most likely cause severe economic disruptions and bring economic growth to a halt.

If Moscow chooses to maintain oil output at any cost, the drain in investment resources probably would undermine goals for economic growth and improvement in consumer welfare, and thereby precipitate bitter disputes in the 1990s. Moreover, tight supplies of both oil and investment resources are likely to tempt policymakers to return to their roles as strong central planners, thereby undermining, or at least distorting, Gorbachev's reform agenda

Appendix A

Prospects for Other New Regions

The Barents Sea

Geologic analysis of Soviet technical reporting indicates that the Barents region could contain 25-30 billion barrels of recoverable oil.[15] Despite this potential, the Soviets have yet to discover a major, commercial offshore oilfield in the Barents Sea. (Peschanoozersk, primarily an onshore field located on Kolguyev Island, has been producing small amounts of oil since 1987.) The Soviets have been actively exploring this region since the early 1980s, but nearly all discoveries reportedly contain predominantly natural gas. Dissatisfaction with the lack of progress in Barents Sea exploration resulted in a major reshuffle of personnel a few years ago. According to recent Soviet press reports, deficiencies in Soviet geophysical equipment and offshore drilling operations in arctic waters continue to impede Soviet exploration efforts, and the Ministry of Geology and the Ministry of the Petroleum Industry are blaming each other for the limited success

Even if Moscow discovers a major oilfield in the next few years, substantial production would be unlikely until at least the late 1990s. Long leadtimes—about five to 10 years—would be required for major offshore development. The Barents Sea poses formidable challenges to any oil development effort. Storms, high seas, fog, snow, and—in some areas—pack ice would hamper development and would increase the difficulty of maintaining drilling and pumping equipment. Even under the best of conditions, this would entail an effort far offshore in arctic waters on a scale never before attempted by the Soviets

East Siberia

Significant production from this region is unlikely in the 1990s. The Soviets have, to date, discovered only limited reserves—about 1 billion barrels or roughly 2 percent of total reserves—and exploration activity remains on a small scale.[16] The geology of this region is particularly complex. In contrast to West Siberia, where many petroleum deposits are large and relatively simple, East Siberia contains much smaller, thinner, and more complex fields. Because of the distance to industrialized centers, the complexity of the reservoirs, and the severe climate and terrain, it is doubtful that the Soviets will mount any major effort to develop East Siberian oil before the next century.

Offshore Sakhalin

Renewed exploratory activity is under way offshore Sakhalin Island. Previous discoveries offshore turned out to be predominantly gas and gas condensate with limited oil reserves. For example, reserves for two offshore fields discovered in the 1970s were reportedly estimated at roughly 300 million barrels of oil and about 1 billion barrels of oil equivalent in natural gas. However, later discoveries, according to Western businessmen, have been mostly oil. The Soviets have recently approached Western firms about joint development of these new fields. Although conditions off Sakhalin Island are severe, some Western firms believe that development would be profitable even with oil prices of $10 per barrel. Even so, these fields are reportedly small, and Sakhalin's contribution to the overall production effort will most likely remain insignificant

[15] See DI Research Paper GI 86-10053 (Secret NF NC), July 1986, *The Oil Potential of the Barents Sea.* (U)

[16] See DI Research Paper GI 84-10139C (Top Secret Codeword NF NC), September 1984, *East Siberian Petroleum Resources.* (U)

Appendix B

Estimating Potential Oil Resources of the North Caspian Basin

Assessing the petroleum potential of a sedimentary basin raises technical problems as well as analytical issues. Even though the North Caspian Basin has produced oil from shallow reservoirs for many decades, the lower section of this enormously deep basin can be considered virgin territory, an oil frontier. Detailed geological and geophysical data are far more limited than would be the case in the West, but fairly abundant compared with data on many other areas in the USSR. Because of the general lack of hard data from actual drilling, our analysis of the oil potential of the North Caspian Basin relied on geochemical theory to provide a framework for assessing the basin's oil resources.

The primary element of the methodology used was geochemical analysis of source rocks. This analysis yields the likely volume of oil generated by, and expelled from, rocks that have proper geochemical characteristics. Because only a small portion of the hydrocarbons generated by the source rocks will ultimately be recovered for commercial use, several steps are needed to arrive at an estimate of the potential reserves of the basin. A series of calculations determines the likely amount of oil or gas generated by the source rocks that gathers in commercial-sized concentrations, known as reservoirs. A recovery factor is then applied to the amount of trapped oil, which reflects the best estimate of the quantity that can ultimately be extracted from the oilfield.[11]

Hydrocarbon Generation

The North Caspian Basin is rich in rocks that are buried deep enough to generate petroleum. Typically, these "source rocks" are organic-rich black shales or carbonates (limestones) deposited under shallow marine conditions and chemically altered by heat after burial. Both carbonates and shales are present in the North Caspian Basin; by some accounts these two types of rock make up 90 percent or more of the volume in the section below the salt layer. Western and Soviet geologic literature indicate that six major source rock units may exist in the North Caspian Basin, three below the prominent salt layer and three above it.

Oil is formed by the chemical decomposition of organic matter in the source rock. The complex molecular chains that make up organisms—consisting primarily of hydrogen, carbon, and oxygen, but including many other elements—are broken down, or "cracked," when subject to heat. This process yields hydrocarbons (simpler molecules containing only hydrogen and carbon) as well as several byproducts such as sulfurous gases. As the source rocks are buried deeper, the rate of formation of hydrocarbons increases; some experts believe the rate may double with every 10-degree (Centigrade) increase in temperature. For example, a given volume of source rock lying at 3,000-meter depths may produce one barrel of oil per year, but rock buried farther—where it is 10 degrees hotter—will produce two barrels per year. As a rule, high temperatures for a short time have an effect on hydrocarbon production similar to low temperatures for a long time. In any case, an enormous length of time is needed to successfully form a significant quantity of hydrocarbons. For example, some of the most significant source rocks of the world—in West Siberia, the Middle East, and the North Sea—are roughly 150-200 million years old. Time is also critical after hydrocarbons are formed. If the generated hydrocarbons are not expelled from the source rock into surrounding rock layers, the heat will continue to crack the molecules until only gas and carbon residue remain. Therefore, given the temperature of the source rocks, a narrow range of time exposures exists for the optimal formation of each particular type of hydrocarbon.

[11] Condensate and gas are not included in this report

Table 5
Estimated Potential Oil Resources of the North Caspian Basin

	Level of Confidence	Weight of Organic Material Converted to Oil [a]	Volume of Generated Oil [b]	Volume Expelled, Migrated, and Trapped [b]	Volume of Recoverable Oil [b]
Total basin	High	247	1,804	144	29
	Medium	380	2,774	236	48
	Low	617	4,507	406	82
Above the salt	High	60	437	35	7
	Medium	92	672	57	12
	Low	149	1,091	98	20
Below the salt	High	187	1,367	109	22
	Medium	288	2,102	179	36
	Low	468	3,416	308	62

[a] Billion metric tons.
[b] Billion barrels.

To relate the time and temperature required to form hydrocarbons to the case of the North Caspian Basin, we used a methodology based on the Time-Temperature Index (TTI), a methodology proposed by Russian scientists and developed by US geochemists in the 1970s. The TTI formula combines geologic temperature and time into a single indicator. Ranges of these indicators are necessary for the generation of different kinds of hydrocarbons. The indicators for each individual source rock unit are plotted on maps of the North Caspian Basin to identify specific areas whose geologic history is consistent with the generation of oil or gas. Combining these areas with estimates of source rock thickness and density, we estimated the quantity of potential source rock present.

Only a small fraction of this source rock is organic material. This percentage is reported in technical literature in a few cases and is supported by examining the likely environments of deposition and by drawing analogies with present environments, giving an estimated percentage of deposited material that is organic in nature. This material, stored in the sediments as they are buried to greater depth, is called total organic carbon (TOC) and can range from 0 to 15 percent or more of the rock weight. We judged likely TOC values in the North Caspian Basin source rocks to be between 1.5 and 3 percent

Only a portion of this organic material has the biochemical characteristics necessary to become hydrocarbons upon heating and aging. This percentage—the generative capacity of the TOC—is estimated by examining the environment at the time of deposition and the likely types of organic material deposited in such an environment. In this assessment, conservative values of the generative capacity were used, which ranged from the minimum capacity that has been scientifically verified to slightly above minimum capacity

The Formation of Oilfields

The expulsion, migration, and trapping processes that form recoverable oil deposits are poorly understood, but experts generally agree that they are very inefficient. As a result, only a small percentage of the oil generated in the source rock will ever be recovered for commercial use, but estimates of this percentage vary considerably. A few researchers believe as much as 20 percent or more of the generated oil is trapped in structures, at least in certain basins where few fractures and faults exist that could serve as conduits for hydrocarbon seepage and loss. But most experts believe that, in an average basin, no more than a small percent of the generated oil will ever be recovered. Because of this large uncertainty, we made conservative assumptions, thereby limiting the chance of overestimating actual recoverable resources.

Expulsion

Clays and associated organic materials that could later become source rocks are deposited on the seafloor in a water-rich matrix. As the sediment is progressively buried—carrying its organic material to the greater depths needed to generate hydrocarbons—water is squeezed out and the clay is compacted, losing considerable volume. Since the process of hydrocarbon generation does not begin until the sediments have experienced nearly all the compaction they will ever undergo, hydrocarbons must escape the source rock by methods other than compaction itself. This can occur through volume expansion of generated gases and liquids and the natural gravitational tendency for lighter oil and gas to migrate upward under pressure from the heavier water. A considerable percentage of generated hydrocarbons will always remain in the source rock, however, especially if it is a shale, and will never be recovered

Migration

Once the oils and gases have been expelled from the source rock, they begin migrating laterally and vertically, following the easiest routes. Along the way, some of the fluids are lost. Some fluids are swept along by underground waters in the beds into which they have migrated, where they remain in uncommercial concentrations or are carried to surface springs and dispersed. In some strata, oil may be lost to commercial exploitation because it clings, in the form of a thin film, to the surface of the grains that make up the rock. But most is probably lost through seepage. When the hydrocarbon fluids reach fractures or faults or strata that are not sealed by an impermeable layer, they migrate upward to the surface and seep away. Seeps are quite common and to this day are one of the easiest-to-spot ways of exploring for possible new oil regions.

Trapping

Because of the losses during migration, only a portion of the hydrocarbon fluids will migrate to a point where they can go no farther because of an impermeable bed above and on the sides of the structure. At these locations the fluids are said to be trapped, and they accumulate in pools that we commonly recognize as reservoirs, or oilfields. Reservoirs consist of porous rocks in which fluids occupy the pore space and can be sandstones, limestones, and other types of rock. They can hold oil, condensate, or gas, and typically contain some amount of all three.

Recovery

The percentage of oil trapped in a reservoir that will be extracted for commercial use is problematic. Ultimate recovery can, in the extreme, be as little as a few percent or more than 90 percent; however, a range of 15 to 50 percent is more common. US operators average only about 33 percent using state-of-the-art equipment and technology and waterflooding methods.

Primary recovery factors for fields in the North Caspian Basin are likely to be about 12 percent. Nevertheless, our methodology is designed to arrive at conservative estimates—in this case a range—of the amount of oil that might be recovered in the long run, including secondary and tertiary recovery.[11] In the North Caspian Basin study, we assumed about 20 percent for ultimate recovery based on the types of fields that have been found to date and their analogies elsewhere. This percentage, though realistic for the

[11] Without extensive technical data on oil reservoirs, arriving at a precise estimate of the additional amount of oil that might be extracted using secondary and tertiary methods is nearly impossible. However, the industry's experience has indicated that adding several percentage points for secondary recovery and a few percentage points for tertiary recovery is a reasonable approach

purposes of this study, may prove somewhat conservative in the long run. Much will depend on the Soviets' ability to install gas injection facilities to maintain reservoir pressure and to monitor gas-oil and oil-water contacts throughout the field as well as their expertise at modeling the reservoir to avoid leaving oil behind. In the history of the Soviet oil industry, there is little to suggest the Soviets are capable of installing a very efficient gas injection infrastructure, especially in fields as large, complicated, and overpressured as those in the North Caspian Basin. Nevertheless, the Soviets have, to date, exhibited a unique determination—backed up by money for Western equipment—to develop the North Caspian Basin with the utmost speed. If this sort of determination spills over into a concern about maximum recovery, achieving recovery factors of about 20 percent should present few technical problems, although it will certainly require large financial outlays.

Appendix C

Tengiz, a Supergiant Oilfield

Our calculations, based on [redacted] and data from Soviet technical journals, indicate that Tengiz is one of the USSR's largest discoveries, rivaling Samotlor in West Siberia. Soviet statements tend to confirm this finding. For example, in early 1988 Soviet Oil Minister Dinkov stated that Tengiz contained roughly 18 billion barrels of oil. He did not specify whether this figure refers to oil in place or to actual recoverable reserves. We believe the figure refers to reserves, partly because it falls roughly in the middle of our estimated range of 9-24 billion barrels for recoverable reserves, and partly because Soviet press reports continue to suggest that Tengiz is a supergiant oilfield.

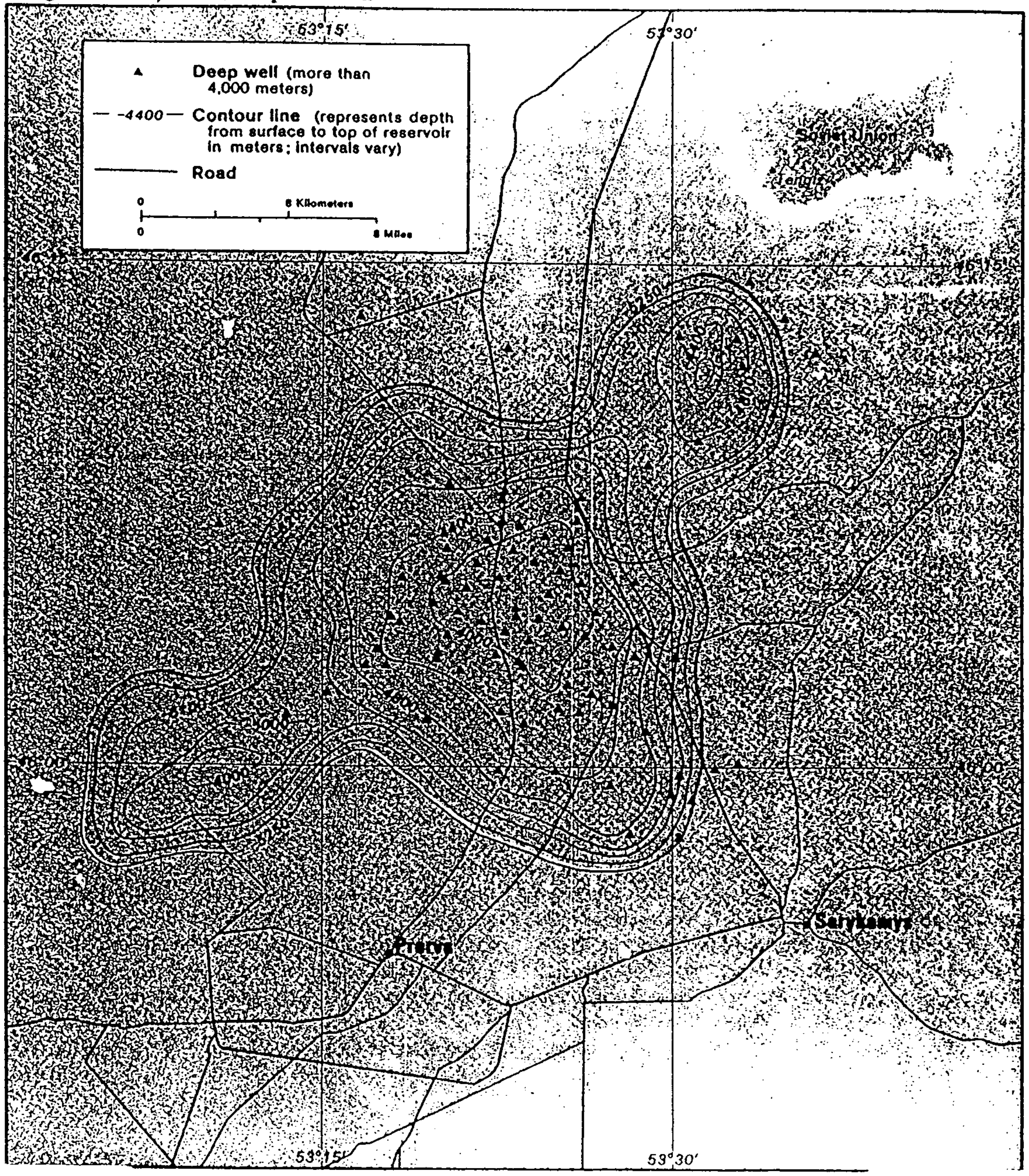
Reserves at Tengiz can only be estimated as a very wide range because Tengiz is not yet fully explored and because it is not a homogeneous reservoir. Such critical factors as porosity and initial water saturation, which have a major impact on calculations of reserves, vary throughout the reservoir and are often presented as ranges in Soviet data. We have created a contour map of the Tengiz reservoir and believe that our estimate for total volume of reservoir rock is fairly accurate (see figure 8). But, because of uncertainty in estimates of porosity and initial water saturation, we can only roughly approximate reserves.

Another favorable characteristic of Tengiz probably will be comparatively high well flows. Soviet technical journals indicate that the reservoir is thick (exceeding 1,000 meters) and that in many places permeabilities, due to fracturing and secondary porosity, are high. In addition, the high formation pressures will provide substantial force to push the oil to the well bore. Some similar deposits in Mexico achieved average well flows of roughly 5,000 b/d.

We cannot be certain, however, that high permeability exists throughout the entire reservoir because the Tengiz reservoir is not uniform. For example, technical analysis of the field frequently refers to three different types of reservoir rocks. Porosities and permeabilities varied significantly, depending on the presence and extent of fracturing. Indeed, extensive fracturing is critical to achieving high well flows. Primary porosity and associated permeabilities (an order of magnitude lower) are so low that well flows are substantially reduced in areas without fracturing. Final evaluation of the extent of fracturing will have to wait for more extensive drilling. Moreover, technical journals report that some bitumen—precipitated out of the oil by heating—exists in some areas of the reservoir and constricts flow channels.

The Soviets also face challenges and additional expense in managing the oil recovery process. Technical journals indicate that gas expansion is the natural mechanism that will bring Tengiz oil to the surface. The reservoir pressures will facilitate this process in the early years of production. Presently, there is substantial difference between formation pressure and bubble point pressure—the point where gas comes out of solution and the fluids lose much of the energy necessary for production. Every barrel of oil that is produced, however, will bring up some of the gas and eventually deplete the natural drive energy. As the amount of oil left in the reservoir decreases through production, decreasing pressure will allow free gas to form and the free gas will flow preferentially through the fractures to the wells, leaving oil behind. Therefore, reinjection of the produced gas into the reservoir is absolutely essential if the natural producing mechanism is to be preserved. Otherwise, the loss of pressure will necessitate the installation of expensive pumps. Even so, injecting gas into the reservoir will require large compressor stations and related manifolds and pipeline infrastructure. The Soviets will have to bear these added costs, or production at Tengiz will suffer.

Figure 8
Tengiz Oilfield, North Caspian Basin



[redacted]

Appendix D

Drilling in the North Caspian: A Look at Two Fields

The great depth of deposits in the North Caspian region puts substantially more strain on equipment and increases the likelihood of breakdowns and delays. For example, the pumps must circulate drilling fluids through as much as 3 miles or more of vertical drill pipe. The great depths also decrease the service life of Soviet drill bits. Additional time is needed to change drill bits and make repairs to machinery and equipment that fail because of use at high stress levels. Furthermore, development drilling in the North Caspian is complicated by the thick layer of salt that overlies the producing formation. This salt layer reduces the chemical integrity and usability of the drilling mud and has a deleterious effect on the cement that is used to seal formations. Because the salt can also behave like a fluid, it seeks to fill the open spaces created by drilling. Special efforts are needed to prevent the collapse of the well casing. To assess Soviet efficiency in drilling into deep, highly pressured formations, we have analyzed in detail—[redacted]—progress at two fields, Astrakhan' and Tengiz.

Astrakhan'

Until recently, the Soviets had little experience in drilling below 4,000 meters. Consequently, exploration and initial development drilling at Astrakhan' proceeded very slowly. [redacted] at least 13 drilling rigs were located at the same well sites as in 1979. This fact, combined with the reported number of exploratory wells completed, implies an average annual penetration rate of about 1,000 to 1,500 meters per rig. At this rate, we estimate that three to four years were required to complete the first wells at Astrakhan'. In contrast, US midcontinent or Texas Gulf coast drillers would be able to complete a comparable 4,200-meter well in less than a year

[redacted] the number of drilling crews had doubled and [redacted] a total of 57 wells had been drilled, 39 of which had been completed and were capable of producing. [redacted] about 16 months is now required to drill a well at Astrakhan'. Another three to four months is probably required to install well head equipment and an on-site separator and flare stack and to connect the well to the gathering system. Thus, we estimate that about two years is needed to drill and complete a well at Astrakhan'. This represents substantial improvement from the rate achieved during the exploration and early development stages.

Even with some recent improvement in drilling rates, Astrakhan' development is three to four years behind schedule. Phase I of the development program, which began in 1981, called for the completion of 56 wells by 1985. We estimate that the Soviets will probably not achieve this target until early 1989.

Tengiz

Drilling at Tengiz is proceeding even more slowly than at Astrakhan' [redacted] the Soviets required roughly two to four years on average to drill and complete the deep development wells at Tengiz [redacted] In some cases, [redacted] the process took five to six years. Although Tengiz was producing about 4,000 b/d in mid-1988, development is already about two years behind schedule. Unless development accelerates sharply, the Soviets are unlikely to meet the 1990 plan—140,000 b/d

We believe that the greater depths and abnormally high formation pressures are responsible for the slow drilling at Tengiz. Depths at Tengiz exceed 5,000 meters compared with 4,000 meters at Astrakhan'. In addition, one of the first wells at Tengiz encountered reservoir pressures exceeding about 13,000 pounds per square inch, about 30 percent higher than at Astrakhan'.

Methodology

Drilling times for all wells—both exploratory and production—include time for site preparation, rigging up, drilling, and auxiliary drilling operations such as cementing and logging; time spent waiting for supplies or repairs; and time for testing formation fluids. Drilling time for production wells also includes time spent completing the well, but not for attaching the flow line.