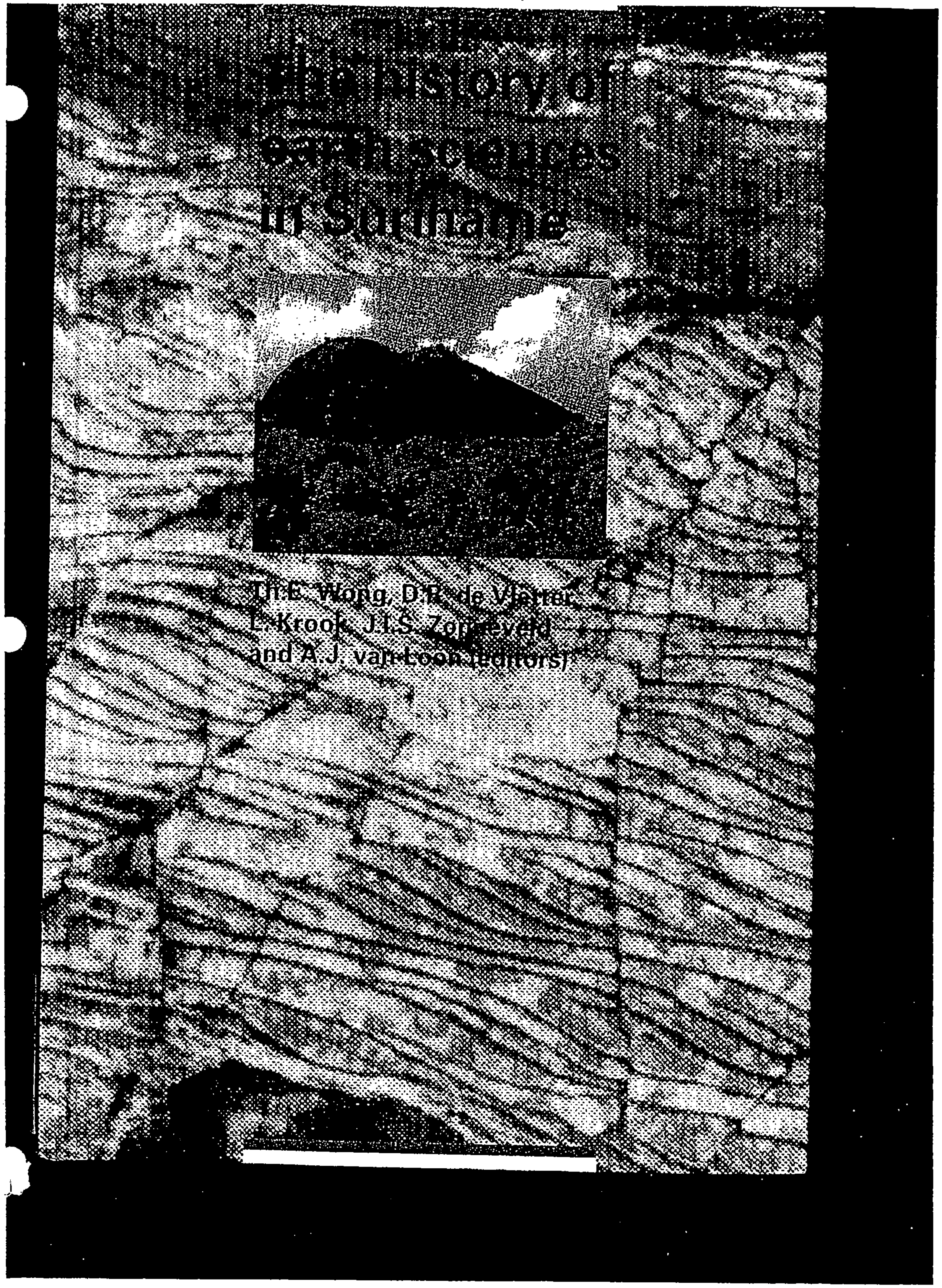
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Amsterdam, 1998

Hydrocarbon exploration and exploitation in Suriname

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Wong, Th.E., 1998: Hydrocarbon exploration and exploitation in Suriname — In: Th.E. Wong, D.R. de Vletter, L. Krook, J.I.S. Zonneveld & A.J. van Loon (eds): The history of earth sciences in Suriname — Kon. Ned. Akad Wet. & Ned. Inst. Toegep. Geowet. TNO, p. 377-393.

Keywords: historiography, oil, petroleum exploration, Suriname.

Abstract

Interest for oil in Suriname was initiated in 1916 when oil seepages were reported to occur in the country. Attracted by these rumours, the Bataafsche Petroleum Maatschappij signed a contract with the locally founded Surinaamsche Petroleum Maatschappij. Based on negative advice, the former denounced their contract in 1927, but the latter nevertheless drilled the first oil exploration well in 1930. This well (T.D. 302 m) failed to encounter economic quantities of oil.

The N.V. Nederlandsch Guyana Petroleum Maatschappij, a daughter of Standard Oil Co. (New Jersey) obtained a concession in 1940. In 1943, after completing a seismic and geochemical survey in the western coastal plain, they drilled well Nickerie 1 (T.D. 1484 m), which reached the Precambrian basement. Since no hydrocarbons were recorded in this well, the company surrendered the contract.

The exploration activity was resumed only in 1957, when the Colmar Surinaamse Olie Maatschappij concluded a contract with the government. The contract was extended in 1960 and 1963 to include the continental shelf. In the same year, Colmar farmed out 50% of its interests to the Surinaamse Petroleum Maatschappij (Petrosur), consisting of Elf, ERAP and EURAFREP. In 1965, the land area of Colmar's concession was surrendered, except for a narrow coastal strip.

In 1965, while carrying out a water-drilling project, the Geological and Mining Service discovered oil at Calcutta (Saramacca district). The reservoir rocks are Miocene sands at a depth of 150-180 m. In the same water-drilling program, comparable oil shows were recorded in wells near Tambaredjo and the Weg naar Zee area in Paleocene sediments, at depths of around 300 m. Follow-up exploration in the sixties by Shell and Elf led to the conclusion that the oil accumulations were economically unattractive and ultimately all onshore acreage was released. The increased petroleum prices in 1979-1980, however,

spurred the foundation of Staatsolie in 1980. This company, fully owned by the state of Suriname, was granted exclusive exploration and production rights in the majority of the Surinam part of the Guiana Basin. After drilling some successful exploration and test wells, Staatsolie started the development of the Tambaredjo oil field in 1982. The initial production rate (200 bopd) increased with time (currently 10,500 bopd). A 55 km pipeline transports oil to a small refinery near Paramaribo. The refinery started operation late 1997.

The heavy, biogradated oil is produced by pumping wells under compaction drive from the T-Sand reservoir, which has an average thickness of 5 m. The ideas on the deposition environment of the T-sand have evolved strongly in time, but it is believed nowadays to be a very complex, highly variable, deposit formed under deltaic to fluvial conditions with laterally and vertically alternating floodplains. The source rock is thought to be a marine black shale of Early Cretaceous age, which occurs offshore. The oil migrated up-dip and was trapped in structural highs created by synsedimentary rejuvenated basement faults in connection with the Bakhuis Horst fault system.

Offshore exploration activities in the sixties and seventies were performed by a group of changing partners, including Colmar, Elf, Shell and Esso. Together they shot about 28,000 km of seismic lines and drilled seven wells, which where all dry. Exploration efforts of Gulf Oil in 1981-1983 were also unsuccessful, albeit that a few, thin, Paleocene sand bodies were found to be oil-bearing. In 1985, the Energy World Trade Group with Austra-Tech as operator evaluated the oil finds of Gulf in more detail by drilling five wells. Although the presence of oil was confirmed, the quantities were considered too small and the contract area was relinquished. Ever since, various oil companies have studied the offshore database but no further exploration took place.

Introduction

The first producing oil well was completed in 1859 by Edwin L. Drake, in Pennsylvania. This achievement stimulated the application of new production methods in both the United States and Europe, which led to the first 'oil boom' in the — then — industrializing world. In the Netherlands, it initiated the interest for the application in the overseas territories. In 1863, E.H. von Baumhauer (professor of pharmaceutics at Amsterdam University) wrote to the Minister of the Colonies, offering to analyse oil samples from the natural seeps occurring in the Dutch colonies. With regard to Suriname, he stated that — though sofar no such seeps had been reported — thorough investigation was warranted in view of the presence of the Pitch Lake at Trinidad and of oil seeps at Cuba, St. Thomas and Ascension. On 28 January, 1864, the Minister replied that in Suriname no such seeps were known to the government (Von Baumhauer, 1868).

The long silence that followed was interrupted only in 1916, by a report of R. Arnold, who had formed an oilhunters group that was investigating Venezuela for the General Asphalt Company. This company was a wholly owned subsidiary of the Caribbean Petroleum Company in which the Royal Dutch Shell Group had taken an interest in 1912. Apparently the eastern Guianas also received the attention in this investigation, for Arnold reported the occurrence of several oil seepages in Suriname.

The coastal plain

Exploration

On 15 November 1926, the Bataafsche Petroleum Maatschappij (BPM), a subsidiary of Royal Dutch Shell, signed a contract with the Surinaamsche Petroleum Maatschappij (SPM). The latter had been granted, on 29 September 1924, an exploration licence covering the whole of Suriname. SPM was owned by B. Koker and A.A.J. Moelaart. They, too, stressed the occurrence of oil seeps in Suriname. BPM requested a Dutch geologist, R. IJzerman, who was carrying out fieldwork in Suriname at the time, to investigate the reported seeps. He proved them non-existent and consequently BPM denounced their contract in May, 1927.

An article by O.M. de Munninck and J.W. Van Dijk in the 'De West' newspaper of 23 November, 1928 presented a rather positive view. The latter author had examined an auger hole on 20 October. This hole had been drilled by W. Houdelet under supervision of government officials. At a depth of 6-12 m, some oil started to float on the cleaned well water when the drill pipe was pulled up. Analysis of three samples led the reporters to the conclusion that, though the kerosene proportion was high (80% in one sample), the oil must be natural. They expressed doubt, however, about the approx. 25% 'fatty oil' in a sample handed in by Koker a few days later. These finds were discussed in more detail by Van Hettinga Tromp (1929), who accepted the natural origin of the mineral oil. As to the fatty oil, he considered a fraudulous addition too improbable to have taken place. A literature survey led him to the conclusion that the non-fatty oil could not have been generated at such shallow depth and hence must have been derived from deeper strata, whereas the fatty oil could have been formed in situ from algae. Since Tertiary sediments had been recorded in the subsurface of British Guiana (now 'Guyana'), he assumed these to be present in the Nickerie area, too. In fact he predicted the existence of petroliferous, Tertiary, strata in the subsurface of the Surinam coastal area! Though he saw no immediate economic viability, he advocated the drilling of a deeper well for purely scientific purposes, because the data provided by such a well might throw some more light on the viability of the various theories on the origin of oil, and might even brighten the economic aspects.

Following the advice of W. Houdelet (advisor of the company after 1927), SPM decided in 1930 to withdraw, after a well had been drilled near Waterloo (Nickerie District). This well had reached a final depth of 302 m in early 1930 (well NN-1, see Figure 1); IJzerman (1931) described samples and reported the presence of some pure asphalt below the depth of 100 m, that made the quartz grains of the sandy host material stick together.

In 1938, the N.V. Nederlandsche Guyana Petroleum Maatschappij, a daughter of Standard Oil Co. (New Jersey), applied for a concession in Suriname, which was granted on February 1st, 1940. It had a duration of forty years and covered approx. 15,900 km² in the coastal plain. Pending the awarding of the concession

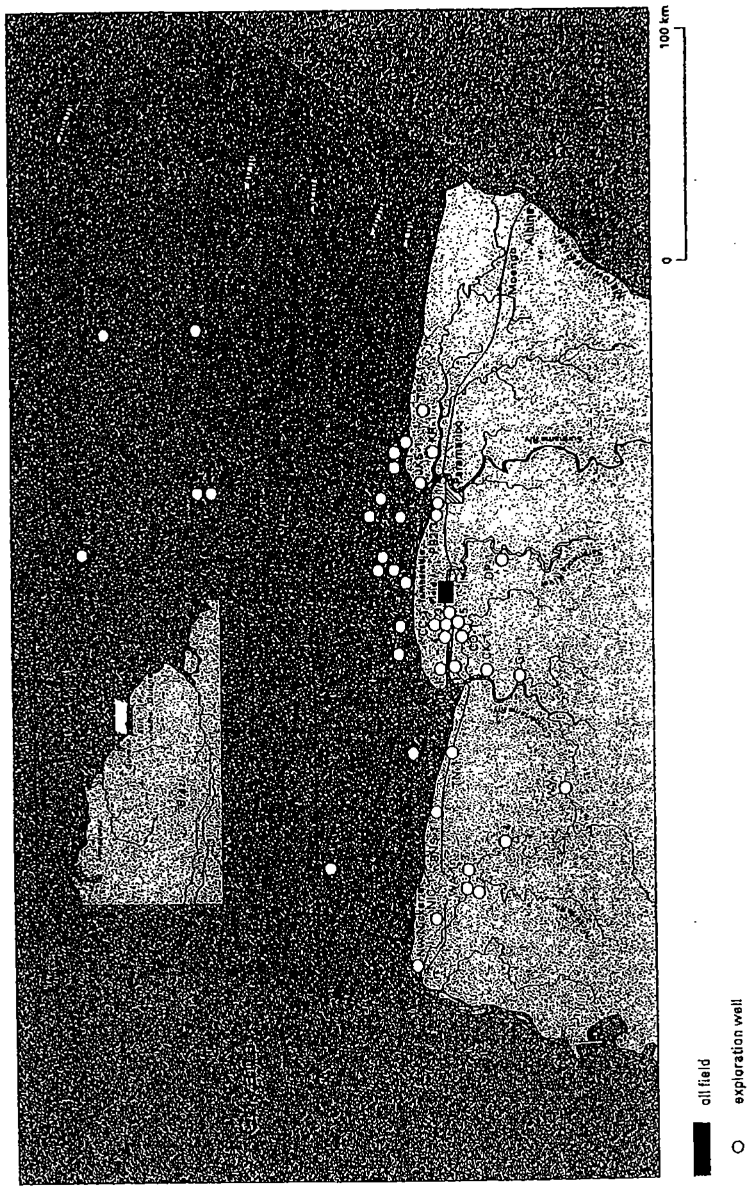

Figure 1: Location of oil exploration wells on the continental shelf and coastal plain of Suriname (marked area on insert). Well A2-1 is located ± 110 km northeast of GLO-1 and could not be plotted on this map.

and based on a temporary exploration permit, the company shot fifteen seismic refraction lines (totalling 435 km) between March 9 and December 3, 1939 (thirteen in a N-S direction and two parallel to the coast). On these seismic profiles, the top of the basement could be clearly distinguished. Except for minor irregularities, it dips some 2 toward the north. The most important irregularity was found between Utrecht and Nickerie. A soil hydrocarbon survey was therefore carried out in 1941 above some small seismic anomalies, tracing methane, ethane and propane at depths of about four metres, hence below the local groundwater level. In addition, a fluorescence survey was made over a seismic anomaly. Some of the samples showed a reaction corresponding with the high values of the soil hydrocarbon survey at that location. Overall, however, the results of the fluorescence survey were very discouraging. Based on the seismic map, the hydrocarbon soil-survey map and the fluorescence map, a location was selected for well NIC-1 (Figure 1). This well reached the basement and a total depth of 1484 m in February, 1943. The company's geologist, Link (1953), reported: "the sediments above the basement complex are continental in origin and showed no indication of oil or gas". In April 1943, Link visited the supposed seepage localities indicated by Arnold, Houdelet and others, but his report was definitely negative and the concession was surrendered still in the same month.

After this negative result, the interest for oil exploration in Suriname faded away for many years. The then Director of the Geological and Mining Service of Suriname (GMD), H. Schols, stated even clearly that the oil prospects were zero for Suriname (Schols, 1952).

The exploration activity was resumed, however, in 1957 when the Colmar Surinaamse Olie Maatschappij N.V. concluded, on January 30, a 40-year contract with the government for an area covering approx. 17,200 km^2 (this area corresponded more or less with the previous concession area of the Nederlandsche Guyana Petroleum Maatschappij). The Colmar group consisted of G.R. Chin Ten Fung (a dentist/politician from Paramaribo), a certain Clayton (a US citizen who owned a gold concession in French Guiana), an American attorney named Hanlon, and still another American, named Marsh, who was the only one in this group with an oil background. With funds largely supplied by Chin Ten Fung, reconnaissance was done onshore at Weg naar Zee, Purmerend and Alliance. The Weg naar Zee site was prepared for one or more drilling locations. In 1958, the American group sold their shares (80%) to Gulf States Lands and Industries Inc., a subsidiary of Webb and Knapp, a New York real estate and investment company. The Colmar group contract was extended in 1960 and 1963 to include the continental shelf. A seismic survey, carried out in 1965 by Western Geophysical Company on behalf of Colmar, also included the Saramacca River coastal area. In March of the same year, Colmar farmed out 50% of its interests to the French N.V. Surinaamse Petroleum Maatschappij (Petrosur), consisting of Elf, ERAP and EURAFREP. In September 1965, the land area of Colmar's concession was surrendered, except for a narrow coastal strip.

On October 15, 1965, while carrying out a water-drilling project, the GMD discovered oil near the school at Calcutta in the Saramacca district (see Figure 2). The oil, with a specific gravity of 0.9486, occurs in a Miocene interval at a depth of 171.2-183.0 m. The well (C-1) flowed after bailing 2.0-2.3 bbl/d. Subsequently oil-saturated sediments were found in four more wells in the Calcutta area (wells C-2, C-3, C-5, C-7), in 1966 in two wells (C-8, C-9) near Tambaredjo some 45 km West of Paramaribo, and in 1967 near Weg naar Zee, some 7 km northwest of Paramaribo. None of these wells indicated that the oil might be economically produceable. The oil from the Tambaredjo and Weg naar Zee areas occurs at a depth of about 300 m in Paleocene strata. During the 7th Guiana Geological Conference in Paramaribo (November 1966), technical data on the various oil occurrences in the coastal plain were presented (an abstract of the presented contribution was published by Coleridge et al., 1969).

The oil discoveries in the coastal plain aroused the interest of several multinational companies. BPM applied for a concession on December 6, 1965. This concession was awarded on November 5, 1968 to Shell Suriname Exploratie en Produktie Maatschappij N.V. In the meantime, in June 1966, this company had already acquired Colmar's (50%) share in the Colmar-Petrosur — largely marine — concession. In 1967, Elf changed the name of its local company 'Petrosur' into 'Elf Suriname Petroleum Co.'. This company drilled four holes at Weg naar Zee in 1968, in their onshore concession, whereas Shell carried out a drilling program (twenty wells) on spread locations in the coastal plain from March, 1969 to June, 1970; the selection of the sites was mainly based on accessibility. The result of all these activities was that the oil finds at Calcutta, Tambaredjo and Weg naar Zee were confirmed, but that no new oil accumulations were found.

With respect to the confirmed finds, Shell (in a report by Noorthoorn van de Kruijff, 1970), concluded that the oil (gravity 13-15° API) could be subtracted by steam soak. The sands were thought too thin, however, to make this economically viable. Consequently, Shell relinquished their onshore acreage on October 1st, 1970.

Gas has been found in several water wells of the GMD: for example, their well near Nieuw Amsterdam produced 34 l/h from 188 m depth, containing 71% methane and 29% uninflammable gas (D'Audretsch, 1953). It is also known that Suralco encountered gas in a bauxite exploration hole at 61 m depth. Recently (1996), Staatolie had a severe blow-out that destroyed their drilling rig at a location north of the Saramacca River. These gas occurrences might, however, at least partly, have a marsh origin. More research is needed to explain the occurrence of free gas in the under-saturated oil of the Saramacca region. The presence of gas underscores the fact that drilling in the deeper part of the coastal plain should be performed with caution with the proper equipment.

Staatsolie

With the establishment of the independent Republic of Suriname in 1975, Venezuela proposed various co-operation projects to the young nation. The Venezuelan oil

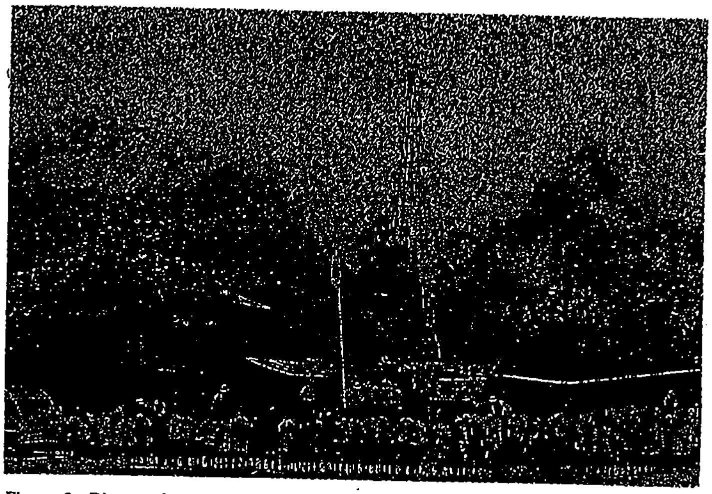

Figure 2. Picture showing the drill-site of the first oil discovery at the school yard of Calcutta (Saramacca District) in 1965 (Photograph by M. Van Loon, courtesy L. Krook).

company, Sociedad Anónima Petroléra Las Mercedes, was asked to assist with the hydrocarbon exploration and exploitation in Suriname. Las Mercedes introduced the principle of the service contract, according to a production-sharing model. Suriname should create, conform the contract, a state company that would own all concessions and that would act as a counterpart for Las Mercedes. Although a concept contract was agreed upon in 1977, it was never ratified by the government of Suriname.

The 'new oil crises' of 1979-1980 and the strong increase of petroleum prices were an incentive for the government to promote petroleum-exploration efforts in Suriname and an Oil Commission was established. This commission formulated new strategic goals, including the foundation of a state oil company. Such a company, Staatsolie Maatschappij Suriname N.V. (fully owned by the government of Suriname), was founded indeed, on December 13, 1980. The geologist S.E. Jharap was appointed director of the new company. The company was given the exclusive right to explore for, develop and produce petroleum, and was granted a concession for the whole of Suriname. The company was allowed to participate in a service agreement with third parties, mostly international oil companies, for the exploration and production of petroleum (see also Jharap, 1981a,b). Staatsolie signed a contract with Gulf Oil Corporation for technical and financial support for an onshore evaluation project in the Saramacca area.

In 1981, Staatsolie drilled three successful evaluation wells (TA-5, TA-6 and TA-7) near the La Prevoyance plantation in the Saramacca area. TA-5 produced, from a depth of 312 m, a total of 160 barrels in seventy hours. In 1982, a 5-well production project was successfully accomplished near Tambaredjo, and on November 25, 1982 Suriname officially became an oil producer.

Ever since, Staatsolie gradually increased its production capacity in the Tambaredjo field (currently covering 28,300 acres), and about 10,500 barrels of oil were produced per day in 1997, from 421 wells. Up to 1997 a total amount of 23 million barrels has been produced. The reserves (1997 figures) are estimated at 900 million barrels total original oil in place, of which 153 million barrels are thought recoverable. Production is by artificial lift, using positive displacement 'screw' pumps. The produced crude is a viscous oil with a low gas/oil ratio, low sulphur and low metal content. It is treated with heat and de-emulsifying chemicals for removal of gas, water and sediment. Initially, about 70% of the oil was sold as fuel to the aluminium industry (Suralco) in Suriname and 30% was exported to a refinery in Trinidad (see also Jharap, 1985). In 1997, approximately 47% of the oil was sold as fuel oil to the local industries, with the major part going to Suralco. The increased export share of 53% still went for the largest part to Trinidad, but other customers included Guyana, Barbados, Antigua, St. Eustatius, Panama, Haiti, Jamaica, Honduras and the USA.

It was decided to construct a grass-roots refinery (capacity: 7000 barrels a day) at Tout Lui Faut, at the site of the Staatsolie export terminal. A 55-km pipeline was constructed for the purpose, from Tambaredjo to Tout Lui Faut. In 1994, Staatsolie managed to finance the refinery project (the total costs were estimated in 1995 to be US$ 57.5 million). US$ 36 million will be financed through loans from ABN AMRO Bank and EFAG, whereas US$ 21.5 million will be taken from the 1995-1997 Staatsolie cash flow. Both the Dutch and the Surinam government will guarantee the loans. The construction of the refinery started in February, 1995 and was completed in August, 1997. The refinery, consisting of a crude-vacuum unit and a visbreaker unit, produces diesel oil, fuel oil no. 6, heavy vacuum gasoil and asphalt.

Petroleum geology

The regional geology of the coastal area was described in detail by Noorthoorn van de Kruijff (1970), Hanou (1981) and Wong (1981, 1984a,b, 1989). There are numerous papers, mostly internal reports prepared on behalf of Staatsolie, dealing with the evaluation of the Tambaredjo Field. Some more accessible general overview articles are from Bergval (1984), Jharap & Bergval (1984) and Wong (1994). The Tambaredjo area appears to be situated in a sedimentary wedge resting on the Precambrian basement. The width of this wedge from coast to basement is about 70 km. The regional environment of this marginal part of the stable Precambrian Guiana Shield has not changed much since the opening of the Atlantic Ocean during the Late Jurassic / Early Cretaceous.

Noorthoorn van de Kruijff (1970) stated that the trapping possibilities of oil in the coastal plain were not supported by structural features and the trapping was believed to be caused by an interplay between the northward flowing shallow groundwater and the southward rising formation water with oil. As Wong (1981, 1984a) remarked, all oil accumulations in the coastal plain (Calcutta, Weg naar Zee, Tambaredjo) are underlain by a structural high of the Precambrian basement that can be considered to represent the NE continuation of the Bakhuis Horst. Faults parallel to this NE-SW trending horst zone continued to be active during Late Cretaceous and Tertiary times, as indicated by the sedimentary section that is also included in the horst structure. The top seal of the reservoir is formed by a continuous clay horizon.

The oil-bearing reservoir sand (locally called 'T-sand') is a basal sand unit of the Paleocene Saramacca Formation, resting on top of an erosional surface at the transition from the Cretaceous to the Tertiary. This transition is marked by a clear increase in rock density in the rock underlying this unconformity. Weathering of the grains is pronounced and cementation is evasive below this surface.

The 'T-sand' is unconsolidated, which makes coring difficult. Only a few feet of core material were retrieved and described by Core Lab (1988a,b). The thickness of the 'T-sand' is highly variable, with a maximum of 14 m. The unit consists of angular, medium to coarse quartz grains with interfingering clays and lignites. The porosity value of these loose sands averages 30%. Frequent avulsion and synsedimentary faulting created a highly compartmented reservoir. The degree of interconnection of the sand bodies is high but clay smears and silting out of the edges confine the reservoir compartments. The sand units with the best potential for hydrocarbon formation and storage, such as channel fills and mouthbar deposits, hardly correlate over more than a few hundred metres.

The ideas on the depositional environment of the 'T-sand' evolved strongly in time, due to the increase of well data. Initially, Noorthoorn van de Kruijff (1970), Hanou (1981), Wong (1981, 1984a,b) and Smith (1985) were of the opinion that the sands represent various overlapping chenier or beach sands. Later, Popek et al. (1985), Ho Len Fat (1986), Core Lab (1988a,b), Kartoredjo, 1987, 1988) and Harris (1989a,b) advocated a fluvial (point bars) origin of the 'T-sand'. Recent studies (Dronkert et al., 1991, Dronkert & Wong, 1992, 1993) revealed that the 'T-sand' is a very complex, highly variable, deposit. The depositional environment could be restricted to distributary bay/channel to fluvial with laterally and vertically alternating floodplain deposits.

In 1990, 44 km of shallow high-resolution seismics were shot (by IGG-TNO) in the Tambaredjo area. The activities consisted of a pilot survey (Meekes, 1990; Goerdajal et al., 1991), after which another survey was carried out more towards the north of the Tambaredjo Field (Van Kuijk, 1991). In this latter study, five wells were used for synthetic seismic reference. The generated synthetic seismics fitted remarkably well on the lines of the seismic survey. The quality of the processed seismic lines is high: a resolution of 2-4 m is possible. Special seismic processing of the seismic data revealed that the reservoir is a very complex system of layers cutting off one another, affirming the model proposed by

Dronkert et al. (1991). From an appraisal point of view, however, the seismic survey contributed little to the areal extent of the field. Generally speaking, however, the Tambaredjo field seems to behave like a rather well-connected entirety, since the average decline of the wells is only 11-12% per year. This can be considered a normal value for oil fields.

Contributions in the form of the engineering reports to the geology are scarce but relevant. Skiba (1987, 1988) stressed that compaction drive is the prominent oil-pressuring mechanism. He also observed that the oil-production rate of several well tests declined much faster than expected. Huurdeman (1990) reached the same conclusion. Dronkert et al. (1991) and Dronkert & Wong (1992, 1993) related this to the highly compartmented configuration of the reservoir.

The oil was thought to be associated with two regional disconformities of Late Cretaceous and mid-Early Miocene age, respectively, which were interpreted as the paths of migration (Noorthoorn van de Kruijff, 1970). Based on the first analyses of the oil, it was assumed that it was the first, low-mature slug from an 'oil kitchen'. The sedimentary section in the coastal plain was never buried to depths of over 2 km and should be considered generally immature with respect to petroleum generation. Moreover, the section does not contain sufficient concentrations of oil-prone organic matter capable of generating commercial quantities of liquid hydrocarbons. In the deeper off-shore part of the basin, however, the Cretaceous section was buried sufficiently deep for a sufficiently long time to reach oil-generating maturity (see the section on offshore geology). Considering the source rocks, several oil companies recently analysed the Tambaredjo oil samples in their geochemical laboratories — for instance Conoco (1997) reported the analytical results of two oil samples from two different wells. It was concluded that: "These oils appear to correlate with each other. Maturity indicators from both samples suggest that the source rock was in the oil window at the time of expulsion. The sulphur contents of both samples are low (0.73 and 0.92%), suggesting a clastic influence and/or high level of thermal maturity. Both oils are composed of about 75% saturate and aromatic compounds, with about 25% nonhydrocarbons and asphaltenes, yet > 90% of the components in the whole oil gas chromatogram are 'resolved unknowns'. That bulk composition is suggestive of oil expelled from a normal mature source rock. The carbon isotopic values suggest a marine origin. Both samples contain relatively low amounts of nickel and vanadium (roughly 30 and 10% respectively), perhaps suggesting some terrigenous input. The biomarker patterns show source rock with more clastic marine input, deposited under saline conditions, no oleanane is present so this is most likely a Cretaceous clastic marine facies".

The produced crude is a heavy, aromatic-napthenic type of oil with a low gas/oil ratio and a low sulphur and metal content. API gravities vary from 13° to 18° and the average viscosity is 1730 cp at 98° F. Generally, the oil is biodegraded, as is indicated by the absence of volatile components and normal alkanes. The type and the chemistry of the Tambaredjo oil were discussed by Cassa (1983).

The most relevant properties of a representative sample of the Tambaredjo oil are listed in Table 1.

It is worth-while mentioning that, although the Tambaredjo field also produces a certain amount of water, the oil/water contact has never been noted (C. Bos, pers. comm.). The water was consequently not derived from an underlying aquifer but may originate from:

- mobilized connate water as a result of compaction drive;
- expulsed clay-bound water as a result of compaction drive;
- overburden water leaking through poorly cemented well annuli;
- underlying water contained immediately below the Top Cretaceous unconformity; this water is not in capillary equilibrium with the oil column, and could not be displaced by the accumulating oil, due to the high oil viscosity and high capillary entry pressures.

Table 1. Properties of Tambaredjo oil sample (Well TA-5).

specific gravity	0.9591	g/cc
API	16.3°	
sulphur	0.80	% wt
nitrogen	0.46	% wt
composition (wt %)		
saturates	35	
aromatics		
mono	13.5	
di	11.9	
tri	2.6	
PNA	13.2	
total	*41.2*	
resins	22.6	
asphaltenes	1.2	
volatiles	0.0	

The offshore area

Exploration

The Colmar company was granted rights in 1960 and 1963 to explore the continental shelf. Since no international ruling existed at the time concerning the seaward boundary of the shelf or the economic zone, this boundary was not detailed, awaiting international settlement. Colmar shot 5245 km of marine seismic lines from 1960 to 1962. On behalf of Colmar, the Canadian Aero Service measured offshore aeromagnetic sections in 1962, roughly perpendicular to the coast and meeting at some 520 km North of Paramaribo. On December 11, 1963, Colmar started drilling their first offshore well (SO-1), with the Western Explorer of Global Marine Exploration Company. The maximum drilling capacity was reached in early 1964, at a depth of 1350 m, in Oligocene sediments. According to a press release of February 27, 1964, the drilled section contained intervals with good porosities and shows of oil; gas was detected in several horizons, though of a non-commercial nature. In order to delineate the location of a deeper well, Colmar shot an additional 6325 km of seismic lines in 1965.

In 1965, the Elf, ERAP and EURAFREP group, through their daughter Petrosur, obtained a 50% partnership in Colmar's concession; offshore drilling, operated by Elf, was resumed in 1966. Two wells were completed: SON-1 (total depth 1925 m) and MO-1 (total depth 1866 m). Both wells bottomed in Eocene sediments and were considered dry holes. In 1966, Colmar sold her remaining interests to Shell. In 1967, well CO-1 (3294 m) was drilled. It reached Maastrichtian-Campanian (Late Cretaceous) sediments. The Tertiary and Cretaceous intervals comprised numerous sandstones with good reservoir properties. In the Cretaceous succession, several oil shows were recorded, which may be why the well was suspended. Operations were resumed in 1971 by the drilling of well GLO-1 (4663 m), which reached Albian (Early Cretaceous) sediments. There were a few oil shows in the sandy Cretaceous succession, yet the well was considered dry. In 1972, some 3810 km and in 1974 some 2300 km of seismic lines were shot, partly covering French Guiana as well.

The French Aquitaine group had meanwhile (in 1973) obtained an interest and had taken over operatorship. In January 1975, the Elf/Shell/EURAFREP group reduced its licence held south of 8° NL from 70,389 to 57,490 km². In April of the same year, Esso acquired one third interest over the Elf/Shell/EURAFREP offshore rights. The new combination drilled well NCO-1 (5406 m), which bottomed in Aptian (Early Cretaceous) sediments, still in the same year. No indications of hydrocarbons were found.

In 1976 and 1977, about 2497 km of seismic lines were shot in the deep, northern part of the Guiana Basin (known as the 'Demerara Rise' or the 'Guiana Marginal Plateau'). In 1978, Esso acted as operator and drilled well A2-1 at a site with a water depth of approx. 1200 m. After drilling through about 3700 m of sediments, the well was stopped in Early Cretaceous strata, without having encountered any commercial hydrocarbon accumulations. After a moratorium period of four years, the group decided to relinquish their entire offshore acreage in 1982.

Exploration activities of Gulf Oil Corporation were initiated in early 1981, in accordance with the service contract between Staatsolie and Suriname Gulf Oil Company. The acreage of the contract area totalled 13,744 km². In 1981, Gulf carried out a seismic survey consisting of 1920 km of deeper-water streamer data and 580 km of shallow-water bottom-drag data. In addition, approx. 1050 km of 1969 Elf seismic data were reprocessed to supplement the new coverage. An infill seismic survey of approx. 1240 km, shot in March 1982, resulted in the identification of three prospects, which were drilled in the second half of the year. All three wells, B/34-1x (1648 m), I/23-1x (4248 m) and L/10-1x (1545 m), penetrated the objective intervals, but they failed to find significant hydrocarbon accumulations. The deepest well (I/23-1x) was aimed at a pre-unconformity level with assumed Mesozoic reservoir rocks. The pre-unconformity section proved, however, to consist of volcanic tuffs and lava flows, with an associated shallow intrusive and with minor volcanoclastic deposits. These lithologies were thought to be identical to the Precambrian rocks of the Marowijne Group. The non-porous igneous rocks terminated the structural stratigraphic potential, the analysis of which had been the primary objective of this well.

In 1983, Gulf drilled six wells very close to the shore in their contract area: L/3-1S (670 m), L/6-1S (727 m), L/1-1S (674 m), L/7-1S (726 m), L/7-2S (631 m) and K/4-1S (681 m). A land rig of Staatsolie was rented for the purpose and mounted on a movable platform. The rig was operated by crews of Staatsolie. The main objective was to evaluate the stratigraphy of the Lower Tertiary. All wells penetrated the Tertiary completely and ended in the uppermost part of the Cretaceous. The onshore Tambaredjo oil field provided an example of the structural-stratigraphic trapping that had been anticipated with these borings in the near-shore region. Three of the wells, L/1-1S, L/7-2S and L/7-3S, indeed encountered thin oil zones within the Lower Paleocene. These accumulations were considered sub-economic and in 1984 Gulf's contract lapsed, after Chevron Corp. had acquired the company.

In 1985, the Energy World Trade Group signed a service/production-sharing contract with Staatsolie for the area previously held by Suriname Gulf Oil Co. The group consisted of Energy World Trade Inc., Northern Michigan Exploration Co., Austra-Tex Oil Co., Suriname Aluminum Co. and some local business people. Austra-Tex was in charge of the field operations. In 1986, this consortium drilled five holes (L/7-3: 1026 m; L/1-3: 614 m; L/8-1: 819 m; L/5-1: 1374 m; and K/6-2: 612 m) to evaluate the Lower Paleocene oil finds of Gulf in more detail. Although the presence of oil in this interval was confirmed (a production test was even carried out in L/1-3), the quantities were considered too low and the contract area was relinquished.

After the Energy World Trade Group had stopped the activities, several international oil companies seriously studied the offshore database. One of these companies was Pecten Suriname Ltd., which signed a service and production-sharing contract in November, 1993. Pecten carried out an extensive study of the offshore contract area and defined a number of prospects. They could, unfortunately, not find a suitable partner for sharing the great exploration risks, and had to relinquish the contract in April, 1995.

Table 2 presents the most relevant exploration data.

Petroleum geology

Due to the negative results of the exploration efforts in the Guiana Basin, only a few papers were published dealing with specific petroleum-oriented topics from this area. Most of the information is in internal reports of the oil companies that

Table 2a. Overview of seismic surveys off-shore Suriname.

company	year	seismic lines (km)
Colmar	1960	5245
Colmar	1965	6325
Elf/Shell	1968-1974	13223
Esso	1976-1977	2497
Gulf	1981-1983	4280

Table 2b. Wells drilled offshore Suriname.

well name	operator	year	T.D. (m)	status
SO-1	Colmar	1964	1350	P & A
SON-1	Petrosur	1965	1925	P & A
MO-1	Petrosur	1965	1866	P & A dry
CO-1	Petrosur	1967	3294	suspended
GLO-1	Elf	1971	4663	P & A dry
NCO-1	Elf	1975	5406	P & A dry
A2-1	Esso	1978	3700	P & A dry
B/34-1x	Gulf	1982	1648	P & A dry
I/23-1x	Gulf	1982	4248	P & A dry
L/10-1x	Gulf	1982	1545	P & A dry
L/3-1s	Gulf	1983	670	P & A dry
L/6-1s	Gulf	1983	727	P & A dry
L/1-1s	Gulf	1983	674	P & A w/oil
L/7-1s	Gulf	1983	726	P & A w/oil
L/7-2s	Gulf	1983	631	P & A w/oil
K/4-1s	Gulf	1983	681	P & A dry
L/7-3	Austra-Tex	1986	1026	P & A w/oil
L/1-3	Austra-Tex	1986	614	P & A w/oil
L/8-1	Austra-Tex	1986	819	P & A w/oil
L/5-1	Austra-Tex	1986	1374	P & A w/oil
K/6-2	Austra-Tex	1986	612	P & A w/oil

carried out an exploration or evaluation programme. An outline of the stratigraphy of the Surinam part of the basin was published by Wong (1976, 1984b; see also Wong et al., 1998, this volume). Lawrence & Coster (1985) published a comprehensive overview of the stratigraphy, basinal setting and prospectivity of the Guyanese part of the basin. Due to the uniform character of the offshore basin development in both countries, their article has also relevance for Suriname.

An important observation by Lawrence & Coster (1985) is that the most prolific source rocks in the offshore area are the widely developed anoxic marine shales of Cenomanian age, which correspond to the Oceanic Anoxic Event-2 of Schlanger & Jenkyns (1976). These shales, which can be regarded as an equivalent of the prolific source rocks of the La Luna Formation in Venezuela, have been encountered in several wells offshore Suriname and Guyana. According to

Lawrence & Coster (1985), these shales occupy a large area, relatively close to the western part of the Surinam coast, in which they have reached oil-generating maturities. Oil generated in this area could have easily migrated up-dip to be trapped in the Bakhuis structural configuration.

Reservoir rocks, mainly sandstones and limestones, are widespread in the Guiana Basin. The main problem is the lack of major, closed, structures at economically drillable depths. Although the presence of major stratigraphic traps (reefs, sand pinch-outs) is to be expected, the offshore part of the Guiana Basin remains a high-risk area, even if state-of-the-art exploration techniques (such as 3-D seismic modelling) are employed.

Acknowledgements

The director of Staatsolie Maatschappij Suriname, Drs. S.E. Jharap, is thanked for his permission to publish data from internal Staatsolie reports. I thank Ir. C. Bos (NITG-TNO) for the critical reading of the manuscript and for his constructive remarks.

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