A PETROLEUM ENGINEERING OVERVIEW OF THE MCKEE FIELD

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The McKee Field, which was discovered during 1979 in onshore Taranaki 14 km southeast of the Waitara township, occurs in an overthrust structure of the Upper Eocene/Oligocene coastal sediments of the eastern Taranaki basin. Appraisal wells drilled between 1980 and 1982 confirmed the field's commercial viability and between 1983 and 1984 more wells were drilled along trend into what were then regarded as the separately defined structures of Pouri, Pukemai, Tuhua and Toetoe. Analysis of well data aided by seismic data acquired in 1985 showed the field to consist of a single reservoir accumulation of oil and gas.

Production of the field commenced in 1984 and by 1986 had reached a rate of some 10 000 barrels of oil per day from 12 wells. In 1986 a full petroleum engineering study, including computer simulation of the field, led to a programme of infill drilling which has maintained production rates and increased recovery by improving the drainage pattern. Reservoir studies to investigate various options for further enhancement of recovery show that natural reservoir depletion with carefully managed offtake rates and gas-oil ratio control provides the best recovery for the field in the medium term. Long term possibilities for recovery enhancement may include tertiary recovery processes such as miscible flooding.

INTRODUCTION

The McKee Field was discovered in 1979 by the exploration well McKee-1 and is located in onshore Taranaki 14 km southeast of the Waitara township (Fig. 1). The accumulation occurs in the sandstone McKee Formation about 2000 m below sea level (TVSS) in one of several overthrust structures found in the Upper Eocene/Oligocene marginal marine sediments of eastern onshore Taranaki. The reservoir is sealed by the overlying marine claystone of the Turi Formation and by the overthrust fault which juxtaposes the reservoir with the Miocene marine claystones of the Mohakitino and Mahoenui Formations.

The field is 100% owned and operated by Petrocorp Exploration Ltd, a subsidiary of the Fletcher Challenge Group of companies.

APPRAISAL HISTORY

The structure was recognised and mapped from seismic reflections off the overlying limestone Tikorangi Formation, 500-600 m above the reservoir (Fig. 2.). In the overthrust, the McKee Formation itself is not resolvable from seismic data on account of steep dips and complex faulting. Early seismic mapping recognised that the structure rolled over from the overthrust fault to form a very steeply southeast dipping flank which could not be accurately located as it was beyond the capabilities of the seismic resolution. Appraisal of the structure was therefore conducted with very poor structural control, especially in the dip direction. Nevertheless the first appraisal well, McKee-2A, which was drilled in 1980, tested at a rate of 1750 stb/d oil and 926 Mscf/d gas. This indicated the presence of a potentially commercial hydrocarbon accumulation so three appraisal/development wells were drilled nearby during 1981 and 1982. They all encountered hydrocarbons and confirmed the field's commercial viability.

Acquisition of further seismic data followed, and during 1983 and1984 eight wells were drilled along the trend into what were then regarded as the separately defined structures of Pouri, Pukemai, Tuhua and Toetoe. All eight wells encountered hydrocarbons and were completed for production.

Initial appraisal and development of the field was completed in 1985 with the acquisition of a close spaced seismic survey and the drilling of three further wells in the Toetoe area.

Subsequent analysis of well data aided by the 1985 seismic data showed the field to consist of a single reservoir accumulation of oil and gas as shown in Fig. 3. This has been confirmed by analysis of the pressure decline and production performance of the field.

DRILLING

The field is located in hilly terrain and this, together with environmental considerations, led to most wells being deviated to their targets from a selection of surface locations (see Fig. 4). The average well deviation angle is some 20° and some wells are deviated up to about 45°.

For the convenience of locating wells within the field, the names of the main original prospects have been retained. Thus, in the southern part of the field the wells are named *Toetoe*, in the centre the wells are all named *McKee* and in the northern area they are named *Tuhua* or *Pukemai*.

The appraisal and early development wells were drilled with a 13-3/8 " surface casing to about 400 m below sea level, a 9-5/8 " intermediate casing to about 1600 m and a 7" pro-

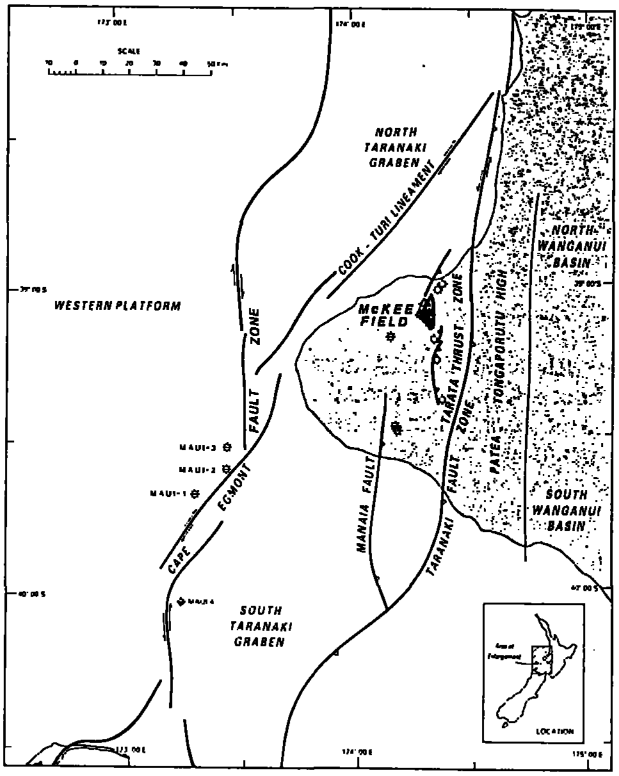

Fig. 1: Major structural elements of the Taranaki Basin.

duction casing string. In later development wells the intermediate casing string was omitted. A contingency string has, however, always been available in case of drilling problems. The casing sizes in the later wells were reduced to a 10- 3/4" surface casing and 5-1/2" production casing. Some of the early wells which penetrated below the McKee sand into the Mangahewa Formation encountered sands which were overpresssured by some 600 psi. In order to minimise drilling mud overbalance on the McKee reservoir and to avoid drilling problems, care is taken to stop drilling soon after the base of the McKee Formation is encountered.

The field's wells have mainly been drilled using a KCl polymer mud system although in a few wells a fresh water mud was used. The KCl serves to inhibit overlying clays and provides a good salinity contrast with the formation water which has a chlorides content of about 18 000 ppm.

Location of wells in positions suitable for completion frequently required that they be sidetracked. Some idea of the difficulties in correctly locating wells in the field may be gained from the fact that on average each well in the field required approximately one sidetrack. The precision required for well targeting is well beyond that of the seismically controlled map and so this task is primarily based on well data. The steep formation dips, typically ranging from 30 to 50° and in some areas in excess of 70°, demand a high degree of deviation precision. Well target tolerances are typically plus or minus 15 m in dip direction.

To date there have been 41 well tracks, including sidetracks, drilled into the McKee reservoir. Data from these well tracks have provided most of the information which makes up the current map of the field. Twenty-four wells have been completed and all but three are connected to flowlines for production.

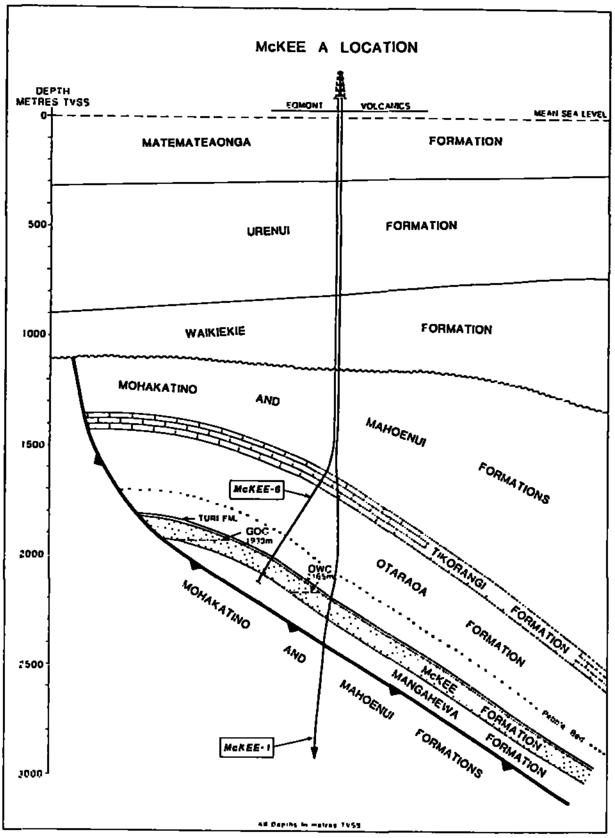

Fig. 2: Typical cross-section through McKee Field.

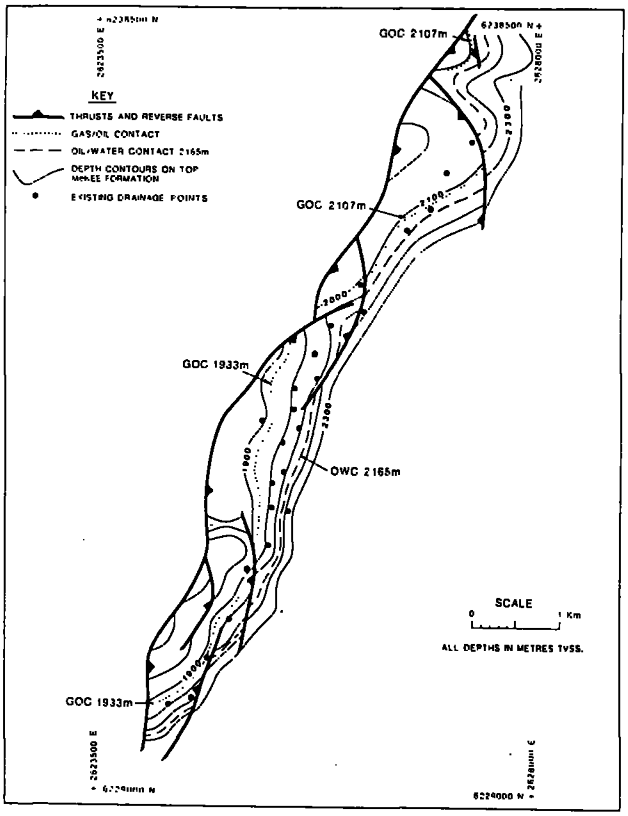

Fig. 3: McKee Field structure map on top McKee Formation.

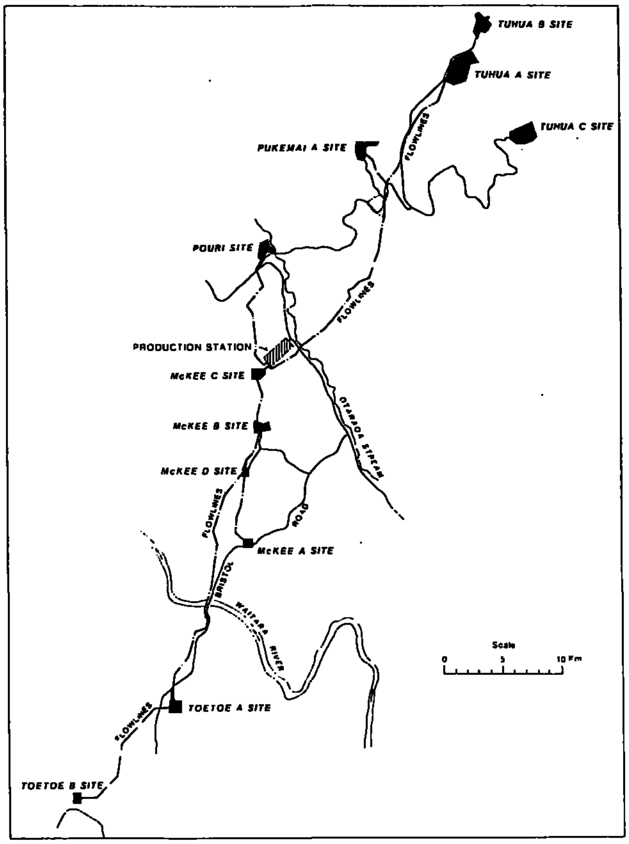

Fig. 4: McKee Field surface site layout.

LOGGING

A standard logging suite of gamma ray, dual laterolog, density neutron, sonic and dipmeter is used in all the wells. In the wells where fresh water mud was used, the dual induction log was also run. The dipmeter has proved to be an essential tool for the detailed mapping of the field to the level of accuracy necessary for the targeting of production wells. The Repeat Formation Tester (RFT) tool was used extensively in the appraisal stage to establish reservoir fluid gradients and thereby determine oil-water and gas-oil contacts. A good example of a typical set of log responses is shown in Fig. 5.

WELL COMPLETIONS

Wells are all completed on a single zone with sets of perforations spaced with blank sections to allow for possible selective plugging of zones at later dates. Tubing, 2-7/8", has been used in all the wells with sidepocket mandrels installed in case of a future requirement to run gaslift valves for artificial lifting.

RESERVOIR GEOLOGY

The McKee reservoir sand was deposited as a coastal sandstone during the late Eocene/early Oligocene. It belongs to the Kapuni Group and represents the last of a series of coastal transgressions and is overlain by the Turi and Otaraoa marine mudstone/siltstone intervals. The McKee sand averages 70 m thick and although superficially it has a homo-

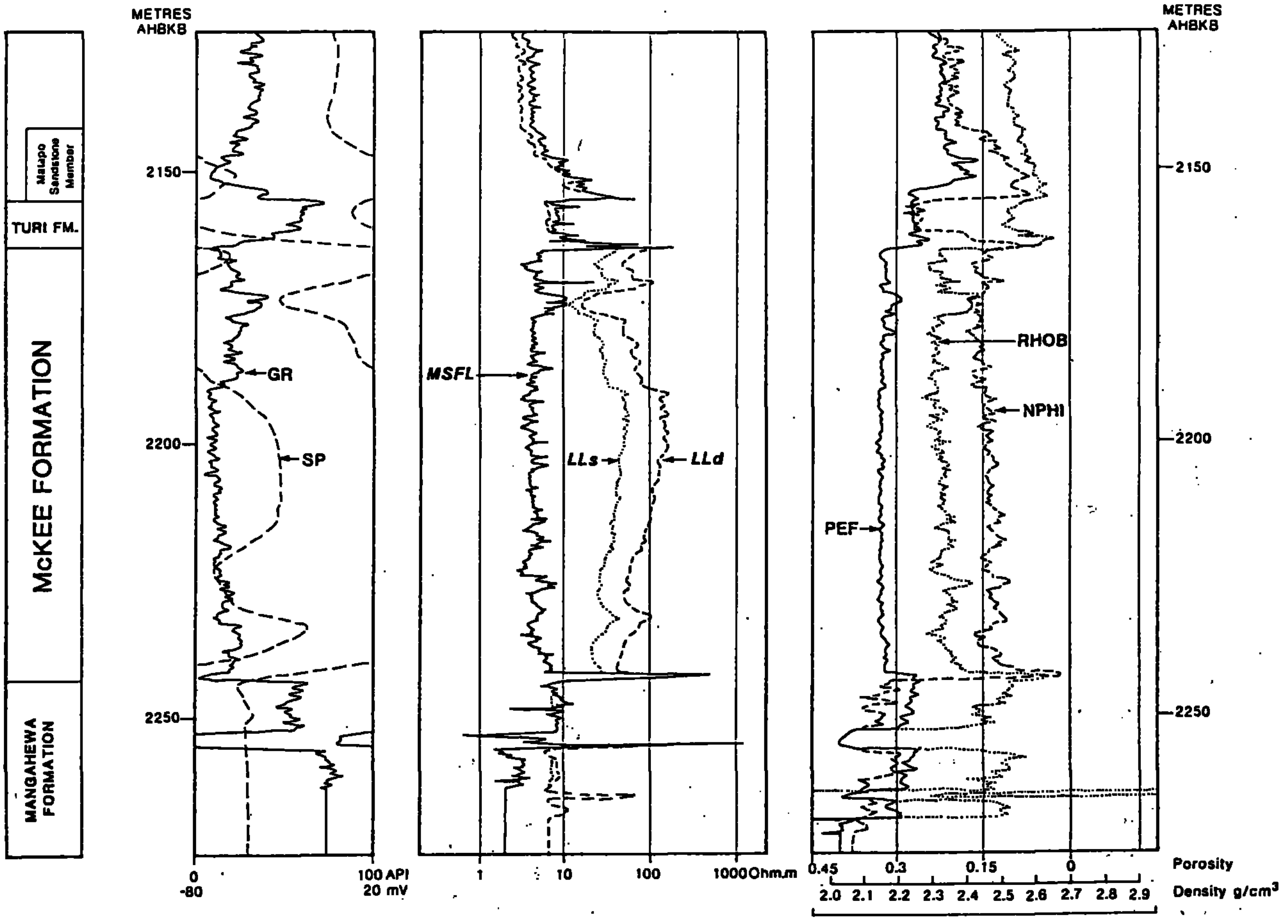

Fig. 5: Typical composite log over McKee Formation.

geneous appearance, it is heterogeneous on a metre scale due to the presence of subtle variations in grain size, thin calcareous cemented beds, small scale healed faults and fractures, and indistinct sedimentary structures. Reservoir quality suffers from significant degradation of primary reservoir properties due to diagenetic processes.

In the northern half of the field the sand is interbedded with a band of shales and thin coal beds which gradually thicken towards the north. This feature is known as the Intra McKee Shale and divides the McKee Formation into the 'A' and 'B' Sands. The 'B' Sand averages 12 m thick and is on average much poorer quality than the 'A' Sand.

Reservoir porosity measurements indicate an average of about 17%. Permeabilities (to air) measured from core samples range up to around 300 millidarcies, with most typical values in the 50 to 100 millidarcy range. Effective permeabilities to oil measured from well tests are mainly in the 20 to 50 millidarcy range. These latter figures are considered to be more representative of the gross effective reservoir properties than measurements from core plugs.

HYDROCARBONS IN PLACE

Evaluation of the well data revealed that the field has two separate gascaps and a common oil-water contact. The gas-oil contact in the northern part of the field is lower than in the south. This results in an oil column in the north which is only 56 m thick, whereas in the south the oil column is 233 m thick. It is believed that these different gas-oil contacts arise from a spill point north of the Pouri-1A well.

Establishment of an oil water contact was not straightforward in the early stages of the field evaluation because there is a large capillary transition zone. An average capillary curve derived from normalised permeability data is shown in Fig. 6. Water saturations, evaluated from logs, exhibited a gradual increase with depth with no obvious water contact. A practical working contact level was established from the RFT pressure data which yielded an average depth of 2165 m TVSS at which the continuous oil phase intersects the continuous water phase.

There is therefore oil found below this oil-water contact (Fig. 6) but, except for occasional isolated pockets (where presumably the reservoir quality is exceptionally good) this is immobile residual oil. McKee-1, the discovery well, was drilled through the residual oil zone and a short well test produced mainly water with no more than 5% oil. The permeability seen from this test was only 0.5 millidarcies. This is one of several indications that there is considerable deterioration of reservoir quality in the aquifer.

In view of this, the 2165 m TVSS level is taken as the effective cutoff for volumetric calculations and serves as a practical level for calculating the lower limits for well completion intervals.

Several factors which can frequently be ignored in volumetric calculation of in place hydrocarbons in many oilfields were found to have a significant effect on the estimates for the McKee Field and are listed below:

(a) Variation of water saturation with depth.
(b) Formation dip.
(c) Overthrust angle.

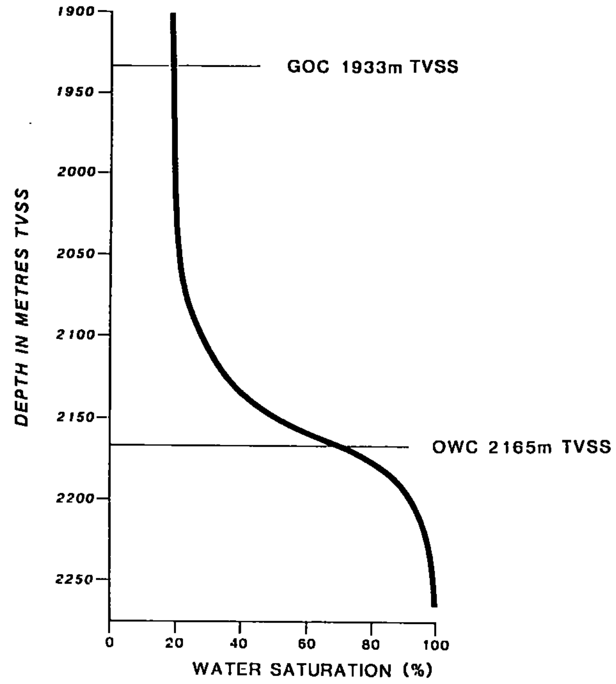

Fig. 6: McKee Field typical water saturation profile.

(d) Correction of core derived porosities and saturations for overburden pressure.

The accuracy of estimates was hampered by lack of accurate knowledge of the angle of the overthrust fault and reservoir quality near the overthrust. There is a lack of well control information in the crest of the structure, near the overthrust. The oil initially in place (STOIIP) is estimated to have been some 106 MMstb and the gas initially in place (GIIP) is estimated at 183 Bscf. This GIIP estimate is based on material balance calculations of the field performance. The volumetric estimate of GIIP is some 40% higher but such a figure is quite unsupportable in terms of the pressure performance of the field. The difference can be explained in terms of the uncertainties near the overthrust fault.

OIL AND GAS PROPERTIES

The McKee Field oil is a waxy crude with an API gravity of about 39°. The pour point is approximately 32°C and sulphur content is negligible.

The associated gas has a gravity of 0.73 (Air = 1) with a carbon dioxide content of 2.8%. The free gascap gas contains a higher CO^2 content than the solution gas. Compared to other Taranaki fields there is a relatively low condensate content in the gascap gas of some 23 stb/MMscf. The reservoir temperature averages 80°C and the initial pressure was 3415 psia at a datum level of 2100 m TVSS. Thus the reservoir was initially about 100 psi overpressured. The measured bubble point for the oil was about 3100 psia but there is some uncertainty arising from the sampling process and there is believed to be some variation of bubble point within the oil column. It is assumed therefore that the oil accumulation was initially saturated (or close to it). Under initial reservoir conditions the solution gas-oil ratio (GOR) averaged some 680 scf/stb and oil viscosity was 0.4 centipoise. This is approximately the same viscosity as the formation water at reservoir temperature and pressure.

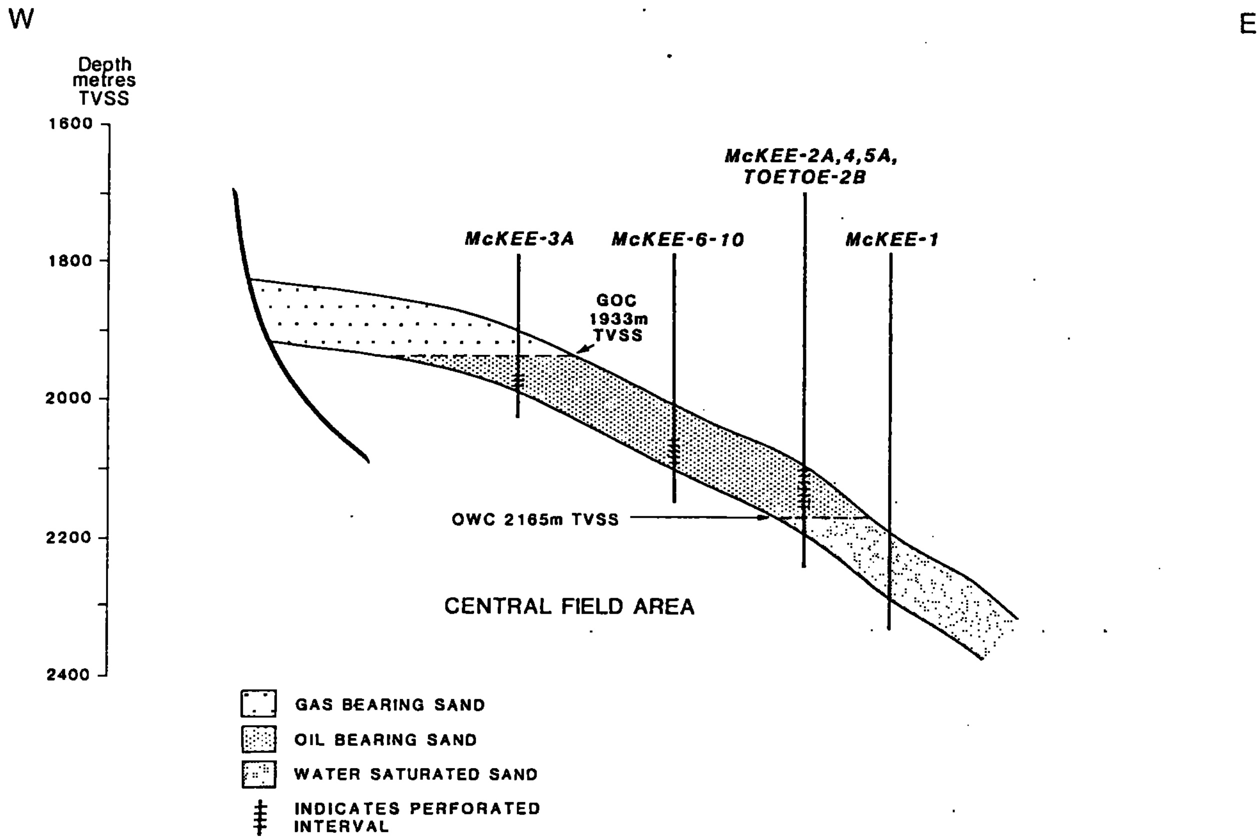

Fig. 7: Typical McKee central area cross-section.

PRODUCTION

Production from the McKee Field commenced in April 1984 through temporary facilities at some 2000 stb/d oil. In November 1984 the field's production station was brought onstream and production was increased to about 5000 stb/d. During 1985 the station's throughput was progressively increased to 6500 stb/d as additional wells were brought onstream. From December 1985 to November 1986 production in the Toetoe area proceeded using temporary separation facilities and road transportation of crude oil. Further expansions to the production station were built during 1986 to accommodate the extra flow from three wells that were producing through the Toetoe temporary facilities. These are now producing through flowlines to the production station. Since 1986 the network of flowlines has been extended to accommodate nine additional wells that were drilled during 1987 and 1988 as part of an ongoing infill drilling programme.

The field is currently producing from 18 wells at about 11 000 stb/d oil, 10.5 MMscf/d gas, with a watercut of 5%. All wells currently flow naturally with no requirement for artificial lifting.

Cumulative production at the beginning of July 1989 was 15.7 MMstb oil, 13.0 Bscf gas and 0.2 MMstb water.

The Production Station comprises two stage oil and gas separation, crude oil stabilisation and a gas treatment system. There are also facilities for treatment of produced water which is disposed of in the Waikiekie (Mt Messenger) Formation at 1350 m TVSS. The current station capacity is some 13 000 stb/d oil and 11 MMscf/d gas.

Oil is piped via a dedicated line to the Omata Tank Farm at Port Taranaki. The associated gas is compressed to 1200 psig and piped to the Natural Gas Corporation's Kapuni pipeline at Tikorangi.

The waxy crude is handled through electrically heated flowlines from the wellheads to production station where pour point depressant is added before piping to Omata. Wax buildup occurs in the upper few hundred metres of the wells and the tubing requires regular wax cutting by mechanical wireline cutters. Investigations are ongoing to find a satisfactory and cost effective non-mechanical means of preventing wax building up in the wells.

RESERVOIR DEPLETION

The main feature of production character is the tendency of the well drawdowns to create a cusp of gas from the gas cap to the wellbore. This may take several years or only a few months to develop depending on how far from the gascap the well completions are located. If unchecked this cusping results in very rapidly rising GORs and a consequent deterioration in oil rates. Such behaviour was observed early in the field's producing life in some of the less optimally placed early wells but fortunately it was found that GORs were controllable provided well perforation intervals were sufficiently far from the gascap.

A representative cross section of the central area of the field is shown in Fig. 7. Well completion intervals are marked and it can be seen that most wells are placed some 120 m vertically from the gas-oil contact. McKee-3A, close to the contact, gassed out within a few months of production and is no longer produced. In the central and southern parts of the field initial well rates were typically in the 1500 to 2000 stb/d range but with the need to control rising GORs most wells have been choked back to lower rates.

A much more difficult production problem exists in the northern part of the field where the oil column is less than 60 m thick. Reservoir quality is not as good as in the central and southern parts of the field so sustained production from these northern wells has only been achieved at low rates typically below 100 stb/d. Methods to improve productivity and recovery from this part of the field have been investigated and the most promising technique appears to be the use of the newly emergent technology of horizontal drilling. It is planned to drill a pilot horizontal well in the McKee Field in the near future.

A representative cross section of the northern field area is shown in Fig. 8. The horizontal well completion concept is illustrated and a visual comparison with the completion intervals of existing wells easily shows that greatly increased productivity can be expected from the longer completion interval. A sustainable production life from a horizontal well should be attainable by producing at lower drawdowns than are feasible in the existing conventional wells.

Computer simulation studies of the field have been ongoing since 1985 and these have played a central role in formulating the optimum development of reservoir drainage and offtake management. Matches of the performance of the simulation models with actual reservoir performance to date indicate that depletion of the central and southern parts of the fields is being dominated by gascap expansion and gravity drainage. This latter depletion mechanism is significant because of the high formation dips and relatively large oil column of the reservoir. It is believed that these natural drainage mechanisms will lead to a relatively good recovery from the field.

The first round of full field simulation studies was concluded in 1986 and led to a programme of infill drilling to improve the drainage pattern of the field. Ten wells have been drilled and completed since1987 with successful results.

The current estimate of oil recovery is 36% of STOIIP which means the field should ultimately yield about 38 MMstb of oil. Possible recovery enhancements from horizontal drilling in the northern area are not included in this estimate.

Investigations have been carried out to see if additional oil could be obtained from pressure maintenance and secondary recovery by water or gas injection.

Gas injection appears to be the most attractive theoretically, but it has been shown by simulation studies that the benefits of displacing oil by additional gas are counteracted by an increased tendency of wells to gas out.

Water injection was found to be impractical because of very poor permeabilities observed in the underlying aquifer. Moreover, the relatively large gascap means that there would be a significant danger of inadvertently displacing oil into the (non oil saturated) gascap where much of it would become unrecoverable. It is believed that the flow of injected water would be too difficult to predict, let alone control, within the oil leg to enable any practical benefit from water injection.

THE FUTURE

The nature of gravity drainage means that the McKee Field will very likely continue economic oil production, albeit at low rates in later years, for at least another 15-20 years. The key to maintaining production and maximizing recovery is to minimise the amount of gas produced during oil depletion. It is currently estimated that some 70 Bscf of gas will be produced with the oil production leaving a potential reserve of about 35 Bscf of gas after oil production has ceased. The recovery estimates given here are all based on recovery by natural depletion and current estimates of residual oil saturations which could yet prove to be conservative. Future

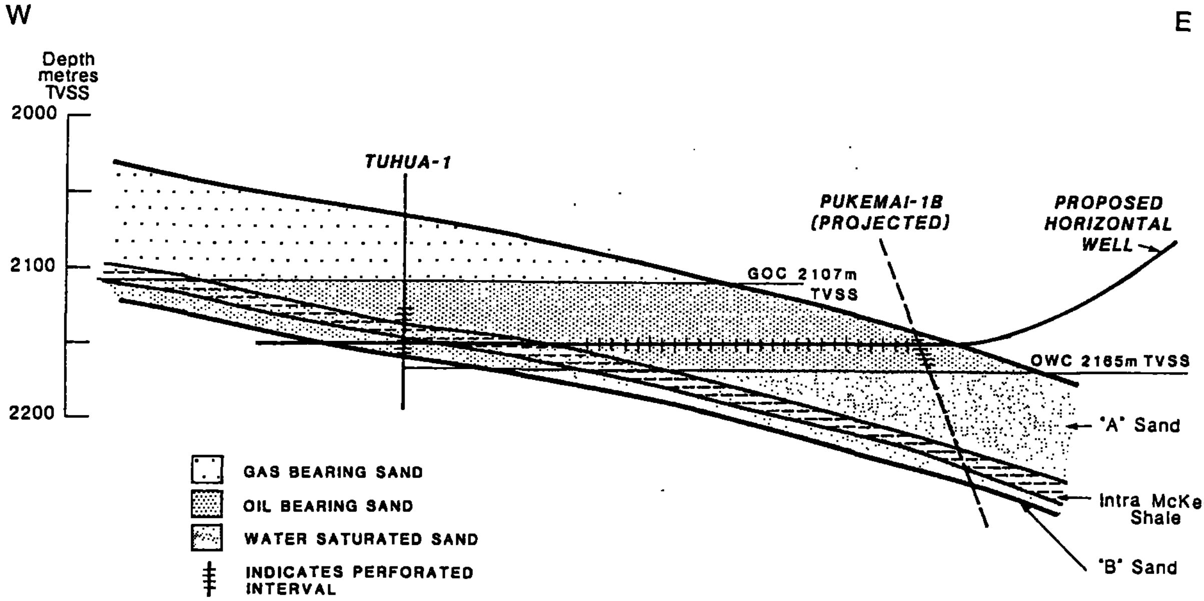

Fig. 8: Typical McKee northern area cross-section.

possibilities for further recovery enhancement lie in tertiary recovery processes such as miscible flooding. Such schemes overseas have had recoveries in the 50-90% range. The efficiency of installing a tertiary recovery scheme in the McKee Field will depend on how the field continues to behave under gravity drainage. It is highly likely that within the next 20 years oil prices and developing technology will enable a significantly greater recovery from the field than is currently economically feasible.

GLOSSARY OF TERMS

AHBKB	Along hole (depth) below kelly bushing
Bscf	Billion standard cubic feet
GIIP	Gas initially in place
GOC	Gas-oil contact
GOR	Gas-oil ratio
MMstb	Million stock tank barrels
Mscf/d	Thousand standard cubic feet per day
OWC	Oil-water contact
psia	Pounds per square inch (absolute)
psig	Pounds per square inch (gauge)
scf	Standard cubic foot (at 14.7 psia and 60°F)
stb	Stock tank barrels
stb/d	Stock tank barrels per day
STOIIP	Stock tank oil initially in place
TVSS	True vertical (depth) sub sea (sea level datum)