THE GEOLOGY OF THE BERUK NORTHEAST FIELD, CENTRAL SUMATRA: OIL PRODUCTION FROM PRE-TERTIARY BASEMENT ROCKS

ABSTRACT

The Beruk Northeast oil field in Central Sumatra was discovered in 1976 by the drilling of Beruk Northeast No. 1 which tested 1680 BOPD from Pre-Tertiary basement. In addition to Beruk Northeast only four other fields are reported to produce oil from Pre-Tertiary basement in Indonesia. Indeed oil production from Pre-Tertiary rocks is very exceptional in Southeast Asia.

Oil production in Beruk Northeast is obtained from fractured metaquartzites, weathered argillites, and weathered granite. The basement reservoirs have K/Ar radiometric dates varying from Early Permian to Early Cretaceous ages which indicate a complex Pre-Tertiary geologic history.

The Beruk Northeast No. 1 well has produced in excess of one million barrels of oil to date. Subsequent development wells have been less productive due to problems of reservoir, separate oil-water contacts and possible unrecognized fracture systems. Beruk Northeast serves as a reminder that the Pre-Tertiary basement is a valid exploration objective in Southeast Asia and that whenever feasible, all exploratory wells should be drilled into basement.

INTRODUCTION

The Beruk Northeast oil field is located within the Central Sumatra Back Arc Basin, which is one of a series of Tertiary basins oriented along the western and southern margin of the Sunda Craton of southwestern Southeast Asia (Figure 1). The Beruk Northeast field is situated within a group of oilfields in the central area of the Pertamina-Calasiatric-Topco Coastal Plains-Pekanbaru Production Sharing Block. The field was discovered in 1976 by the drilling of Beruk Northeast No. 1 which tested oil from fractured Pre-Tertiary metaquartzite basement rocks.

DEFINITION OF BASEMENT ROCKS

The term "basement rocks" generates a variety of definitions by geologists depending on the specific sedimentary basin discussed as well as the individual's experience in that area. Most workers consider basement as any metamorphic or igneous rocks (regardless of age) which are unconformably overlain by a sedimentary sequence. Oil may have migrated into older porous metamorphic or igneous rocks thereby forming a basement reservoir. However, in some basins as the Central Sumatra Basin, the basement rocks may be partially or completely unmorphosed. Therefore the authors of this paper prefer the Landes et al (1960, p. 1682) description of basement, as stated: "The only major difference between basement rock and overlying sedimentary rock oil deposits is that in the former case the original oil-yielding formation (source rock) can not underlie the reservoir". A final comment on the definition of basement rocks is that further exploration, geological and geochemical studies in a specific area may result in revisions of the commonly accepted definition of basement rocks within that area. Further exploration may indeed prove the existence of hydrocarbon source rocks located stratigraphically within rocks previously regarded as basement. Accordingly explorationists' definition of basement rocks can not be rigid but must be responsive to new geological ideas and data.

AREAS OF BASEMENT OIL PRODUCTION

Basement rocks are important oil reservoirs in various areas of the world. Basement reservoirs occur in Venezuela and Brazil in South America; Libya, Algeria, Morocco, and Egypt in North Africa; the Cuanza basin of Angola in West Africa, and the West Siberia basin of the Soviet Union (Chung-Hsiang P'An, 1982). In the United States, basement-derived oil production occurs in a number of areas, including California (Wilmington and Edison Fields), Kansas (El Dorado and Orth Fields), and Texas (Apo Field).

East Asia had no significant basement hydrocarbon production until the discovery in 1959 of oil in fractured metamorphic rocks of Silurian age in the Yaerxia Field, Yumen, China (Chung-Hsiang P'An, 1982). During the 1979's about 20 prolific basement reservoirs were discovered in the Bohai Bay basin, offshore China. Production is from Paleozoic and Proterozoic limestones in structures commonly known as "buried hills" (Yan Dunshi and Zhai Guangming, 1980). Paleocene black shales are the reported oil source rocks for the Bohai Bay reservoirs (Li Guoyu, 1981).

Almost all presently known oil and gas fields in Southeast Asia are located in Tertiary sediments. In most cases, the oil and gas accumulations occur in Neogene age formations.
(Fontaine and Mainguy, 1982). In Southeast Asia rocks of Pre-Tertiary age are generally regarded by explorationists as economic basement. Although the Pre-Tertiary series produces significant volumes of oil and gas in Australia and in China, the area between these two continents has almost been devoid of production from the Pre-Tertiary. Severe tectonism and deformation experienced by Southeast Asia prior to deposition of the Tertiary has decreased the prospectiveness of the Pre-Tertiary series and in many areas the Pre-Tertiary is thermally overmature for oil preservation.

The poor production history of the Pre-Tertiary in Southeast Asia must also be partially attributed to the absence of exploration specifically aimed towards evaluating the Pre-Tertiary's potential. In this regards, the very recent discoveries of gas in Pre-Tertiary rocks in northeast Thailand is significant. A gas flow rate of 27 MMCFD was reported from Permian limestones in the Esso Nam Phong and Chonbhot wells. These gas discoveries are in a large basin that has experienced minimal drilling to date (Oil & Gas Journal, 1982).

Basement Oil Occurrences in Indonesia

In addition to Beruk Northeast, four other Indonesian oil fields produce from Pre-Tertiary basement rocks (Figure 2). The following occurrences of basement oil production have been reported in the literature:

1. The Kluang Field in South Sumatra has produced oil from Pre-Tertiary rocks and from the Tertiary Talang Akar Formation (Martin, 1952). Oil occurs at the top of the Pre-Tertiary in a limestone paleotopographic high similar to the Chinese "buried hills". Severe weathering prior to deposition of the Tertiary resulted in excellent secondary porosity. The amount of oil produced from basement is not reported.

2. In the Sei Teras Field, South Sumatra, 15,000 barrels oil and 1 BCF gas has been produced since 1977 in two wells from basement limestone and quartzite (Tiwar and Taruno, 1979).

3. Approximately 21 million barrels of oil and 14 BCF of gas has been produced from Pre-Tertiary rocks in the Tanjung Field, South Kalimantan (Tiwar and Taruno, 1979). The basement rocks in this field consist of porphyritic extrusives and volcanics as well as metamorphosed sandstones, shales and claystones. In both the Sei Teras and Tanjung Fields the basement is locally deeply weathered and fractured. Mid-Tertiary sediments are regarded as the likely source rocks for both fields.

4. In eastern Seram oil is produced from Pleistocene sediments and fractured basement (Bula Field), Pre-Tertiary limestone (Nief pool) and Pre-Tertiary sandstone and siltstone (Belien pool). Zillman and Pater (1975) regarded the Tertiary as the likely source for the Seram oils whereas Fontaine and Mainguy (1982) have suggested the Seram oils are probably derived from Triassic source rocks.

Due to the paucity of basement oil production in Southeast Asia, the Beruk Northeast oil field will hopefully be of interest to the petroleum industry and the earth science community in Indonesia and Southeast Asia.

REGIONAL GEOLOGICAL SETTING

The Beruk Northeast field is located 60 km east of the Minas field in the Calasiatic and Topco Coastal Plains Production Sharing Contract Area which is operated by PT Caltex Pacific Indonesia. Fourteen oil fields have been discovered in the contract area since 1971 (Figure 3, 4). All fields in the Coastal Plains produce from Sihapas sandstones and conglomerates except the Beruk Northeast field which produces from fractured metaquartzite, weathered granite, and weathered metasediments. Beruk Northeast is the only field within Caltex's area of operations in Central Sumatra which produces oil from basement.

Regional Tertiary Stratigraphy

Tertiary sedimentation in the Coastal Plains area commenced in Paleogene time with the deposition of Pematang Formation sediments on the Pre-Tertiary erosional surface. A stratigraphic column is included for reference (Figure 5). Cross sections based on well control (Figure 6) and seismic isochron mapping indicates that considerable paleotopographic relief existed on the Pre-Tertiary surface prior to deposition of the Tertiary. The correlation of well data illustrates the thick infill of Pematang into the Bengkalis paleotrough eastwards of the Beruk Northeast field. The Beruk High remained positive throughout the Pematang depositional cycle and is devoid of Pematang sediment. Adiwidjaja and Decoster (1973) described similar paleotopographic relief on the Pre-Tertiary surface in South Sumatra.

The Pematang Formation consists of varicolored and mottled claystones and fine to coarse sandstones and conglomerates of continental origin. The Pematang is separated from the overlying Sihapas Group sediments by a regional unconformity which is marked by dip truncations on some seismic lines in the area. The transgressive phase of the Neogene cycle is represented by the Sihapas Group and the Telisa Formation. The Sihapas sediments are fine to medium grained sandstones interbedded with silty grey shales. Well logs, cuttings and core data suggest a fluvio-deltaic depositional environment and the intermittent presence of glauconite in the Sihapas rocks inter marine influences. The continuation of the marine transgression is marked by the dark grey shales, minor thin fine grained sandstones and limey interbeds of the Telisa Formation. The Telisa is overlain by Petani Formation claystones and sandstones which represent the regressive phase of the Neogene cycle. The Neogene is overlain by a thin veneer of Holocene Minas Formation alluvium.
For further details about the Central Sumatra Tertiary sedimentary section, the reader is referred to earlier publications by Mertosono and Nayoan (1974), Mertosono (1975), and Hasan et al (1977). Lee (1982) described the Tertiary succession in the Malacca Straits area located on the northeastern margin of the Central Sumatra Basin.

Regional Basement Rocks

The basement rocks of the Central Sumatra basin were reviewed by Eubank and Makki (1981). Since this publication several recently drilled exploratory wells have provided additional significant basement information (Table 1).

1. The Cucut No. 1 well was drilled in October 1981 and cored unmetamorphosed greywackes ("pebbly mudstones") containing abundant angular to sub-rounded clasts of granitic, volcanic, and metamorphic composition (Figure 7). This rock is believed to represent the Carboniferous Bohorok Formation (Tapanuli Group) which crops out along the mountain front west of the Central and North Sumatra Basins. Cameron et al (1980) stated that "the age of the oldest parts of the Kluet and Bohorok Formations is unknown, and it is possible that future work will identify rocks of Devonian or possibly Early Paleozoic age within the Tapanuli Group as defined at present".

Palynological, and radiometric age dating by Chevron Oil Field Research Company (COFRC) supports the above Cameron et al (1980) statement. The clay mineral matrix was dated by palynology as Early-Middle Carboniferous. No marine palynomorphs were recovered, thus suggesting a nonmarine depositional environment. A granite dated within the matrix provided a K/Ar radiometric age of uppermost Devonian (348 ± 10 M.Y.). The distinctive polymictic lithologic character of the Cucut No. 1 core appears to support Cameron et al's (1980) assertion that the "pebbly mudstones" of the Bohorok Formation represent the reworking and turbiditic redeposition of ice-rafterd, subglacial or fluvio-glacial debris. However, the palynology recovered from the core contained none of the highly distinctive Gondwana or glacial flora of Late Carboniferous, Permian or Early Triassic age. Further drilling in the Cucut area may provide more information to resolve the origin of these interesting basement rocks.

The total organic content (TOC) of the Cucut core is very low (0.25 wt %) indicating that the sample has little source rock potential. H/C ratios and vitrinite reflectance measurements (Ro > 1.9) suggest that the organic matter is thermally postmature.

2. Pusaka No. 1, cored dark grey, slaty, silty, fractured shales (Figure 7). On the basis of palynology, COFRC estimated the age of the shales to be near the Devonian/Carboniferous boundary. The Thermal Alteration Index (TAI) of the organic material within the shales ranged from 3.5 to 4.0 which approximately coincides with the dry gas generation stage.

3. Idris No. 1 encountered hydrothermally altered granite in a bottom hole core (Figure 7). This well was drilled in 1982 and is located within 10 km of the Beruk Northeast field. K/Ar radiometric age dates of 208 ± 7 M.Y. were obtained from muscovite, 206 ± 8 M.Y. from albite, and 101 ± 4 M.Y. from microline. The COFRC interpretation of the data is that the muscovite and albite indicate a minimum age of granite emplacement of about 200 M.Y. (Late Triassic or Early Jurassic). The microcline constrains a post emplacement thermal event younger than 100 M.Y. (Late Cretaceous or Early Tertiary).

Rb/Sr isotopic data was obtained to supplement the K/Ar age data. Rb and Sr data better preserve the true formation age of a rock because these two elements are less disturbed by young thermal events than K and Ar. K/Ar age dates represent the time of latest metamorphism. The K/Ar "clock" is reset each time a rock is raised to high temperature, even if partial melting does not occur. Rb/Sr dating provided an age of granite emplacement of 295 ± 3 M.Y. (Late Carboniferous). The initial Sr isotopic ratio indicates that the Idris granite formed by the melting of pre-existing rocks which themselves experienced a long continental history. In conclusion, the radiometric and petrographic data indicates that Idris No. 1 penetrated basement that has had a very long and complex geologic history. The Idris No. 1 data are relevant for the Beruk Northeast field since granites of similar age and composition occur in several of the field wells.

FIELD DEVELOPMENT

The Beruk Northeast Field was discovered in 1976 by Beruk Northeast No. 1 which was drilled to a total depth of 1634 feet into Pre-Tertiary basement to test a structural closure defined by seismic (Figures 8, 9). The main objective Sihapas sandstones were absent and Telisa shales with minor sandstone interbeds lie directly on Pre-Tertiary basement. Beruk Northeast No. 1 penetrated 28' of heavily fractured metaquartzite basement with oil shows in the cuttings, bottom hole core, and in side-wall cores. An open hole test of the basement flowed 1680 BOPD (38.6° API gravity and 115°F pourpoint). A thin Telisa sand (named the Telisa 1500-foot sand) located approximately 100 feet above basement was tested and flowed 480 BOPD (38.3° API and 120°F pourpoint).

To delineate the lateral extent of the oil-bearing basement and also to test the potential of Sihapas sands onlapping and pinching out against the basement high, Beruk Northeast No. 2 was drilled in mid 1976 approximately 1.5 Km northeast of Beruk Northeast No. 1. The well bottomed in granite basement at a total depth of 1941 feet. An open hole test of the granite proved the basement
to be tight; the Sihapas sandstones were porous and water-bearing.

Beruk Northeast No. 3 and No. 4 were drilled in mid 1982 to provide additional development well control for the field. Beruk Northeast No. 3 confirmed oil production from weathered arenaceous argillites. Beruk Northeast No. 4 tested oil from a basement sequence consisting of weathered hornfelsic argillite and granite.

Beruk Northeast No. 5 was drilled in late 1982 and tested 2252 barrels fluid per day (34% water cut) from an open hole test covering 14 feet of fractured metaquartzite basement. Severe lost circulation problems prevented the drilling of this well deeper into the objective basement rocks.

FIELD GEOLOGY

Basement core data in the area of the Beruk Northeast Field indicates a wide variety of basement rock types and a broad range of radiometrically dated ages. Although the Beruk Northeast wells cover a small area of less than 5 square kilometers, the variability in rock types and ages indicates a very complex Pre-Tertiary geological history.

The rocks can be subdivided into three broad categories on the basis of lithology and K/Ar age dates, as follows:
1. Metaquartzites of Early Permian age (Beruk Northeast No. 1 and No. 5).
2. Granites of Late Triassic to Early Jurassic age (Beruk Northeast No. 2 and No. 4, Bungsu No. 1, Idris No. 1).
3. Argillaceous metasediments of Early Cretaceous age (Beruk Northeast No. 3 and No. 4).

Reconstruction of the Pre-Tertiary geological history of the Beruk Northeast field is difficult due to the inaccuracies inherent in the K/Ar radiometric age dating method as discussed previously. To obtain a more accurate insight into the Pre-Tertiary history preferably all basement cores should also be dated by the Rb/Sr method.

Beruk Northeast Structural Growth History.

The growth history of the Beruk Northeast structure during Tertiary time is evident on stratigraphic cross-sections and key seismic lines (Figures 8, 9 and 10). Paleogene Pematang Formation and Miocene Sihapas Group sediments are absent on the crest of the structure, indicating that major structural growth had occurred prior to deposition of the Paleogene. The isopachs of the Telisa 1500-foot sand to the Top Pre-Tertiary in wells No. 1, 3, 4 and 5 are almost identical suggesting that the Pre-Tertiary surface was relatively flat before deposition of the Tertiary (Figure 10). Stratigraphic cross-sections infer that the Beruk Northeast structure was a relatively small basement "island" standing some 30 feet above the wave base during late Sihapas time. Consequently the Beruk Northeast basement high is "bald" or devoid of the Sihapas Group sands which are the producing zones in all other Coastal Plains Block fields.

The consistent thicknesses of the units between marker beds in the Telisa indicate that structural growth was active during Telisa time. However, the seismic lines show the expression of the Beruk Northeast structure in beds almost at surface, thereby indicating that rejuvenation of structural growth occurred during the Plio-Pleistocene orogenic phase. This late movement placed Telisa Formation beds, as the Telisa 1500-foot sand, into structural closure (Figures 11, 12).

FIELD RESERVOIRS

The Beruk Northeast field produces oil from fractured metaquartzite (wells No. 1 and No. 5), weathered argillite (well No. 3) and weathered argillite and granite (well No. 4). Minor oil production is obtained from the Telisa 1500-foot sand in wells No. 3 and No. 4. Telisa shales are the cap rocks above the basement reservoirs. The reservoir had an original reservoir pressure of 680 psi. The reservoir temperature is 200°F and connate water saturation averages 37%.

Defining oil pay zones in basement by the electric logs is difficult. Refer to the composite log of well No. 4 which shows typical log response in basement (Figure 13). Oil pay zones are initially detected by drill cuttings analysis. After the wireline logs are obtained, numerous sidewall cores help to further define the pay zones. Since the cuttings and sidewall cores analyses are very important, accurate lithology and oil show descriptions from the wellsite geologist are utilised on all Beruk Northeast wells. Wireline and swab test from many intervals are the final bases for defining producible hydrocarbon and water zones.

The "Top Basement" structure map (Figure 14) shows that the Beruk Northeast structure is broken into a series of north-south oriented fault blocks. Most of the faults do not extend into the overlying Telisa section (Figure 12). Beruk Northeast wells No. 3 and No. 4 were drilled into separate fault blocks. A common oil-water interface is absent in wells No. 3 and No. 4, thereby suggesting that either the fault separating these two wells is a sealing fault or the reservoir is discontinuous between the wells. The oil-water contacts are unknown in wells No. 1 and No. 5 since neither well penetrated the oil-water interface.

The oil produced from the Beruk Northeast basement reservoirs has a average gravity of 38.3 degrees API and a pourpoint of 115-120 degrees Fahrenheit, which is similar to the gravity and pourpoint of most other Coastal Plains oil fields. The Beruk Northeast oils are probably derived from the same rich Tertiary shales source rocks as the other Coastal Plains oil fields. Oil presumably migrated away from the source area through Sihapas sands or along the Pre-Tertiary unconformity surface into the Beruk Northeast basement high. Faults may also act as conduits for oil migration in this area.

FIELD PRODUCTION

Beruk Northeast No. 1 was placed on production in
early 1981. Initial production averaged about 2200 BOPD (0.2% water cut). Figure 15 summarizes the production performance of this well. Decreasing oil production together with increasing water production has resulted in a relatively constant produced fluid gross, indicating that the fault block drained by this well has a very active water drive. Formation pressures declined only 30 psi after one year of production. To date Beruk Northeast No. 1 has produced in excess of 1,100,000 barrels oil, 640,000 barrels water and 42 MMCF associated gas. All production from this well is evidently obtained through the naturally-occurring fracture system in the Pre-Tertiary metaquartzites since negligible matrix porosity exists in the core.

Beruk Northeast No. 3 and No. 4 went on stream in 1983 at initial production rates of about 200 BOPD and 25 BWPD. The relatively low production rates (compared to well No. 1) are due to the poor reservoir characteristics of the weathered argillite and granite reservoirs.

Beruk Northeast No. 5 began production in 1983 at an initial rate of 300 BOPD and 40 BWPD, however within 3 months this well was producing 100% formation water. Although this well is located within 900 meters of Beruk Northeast No. 1 and produces from a reservoir lithologically identical to the Beruk Northeast No. 1 reservoir, the production performance has been totally different between these two wells. Beruk Northeast No. 5 has probably penetrated a fault block with an oil-water contact structurally higher than that in the Beruk Northeast No. 1 fault block. The discontinuity of the oil-water contact between these wells is probably due to the discontinuous nature of the fracture network. Alternatively, the presence of an unrecognized water-bearing fracture system in Beruk Northeast No. 5 may have caused a sudden water influx into this well.

CONCLUSIONS

This paper describes the hydrocarbon potential in Pre-Tertiary basement rocks in Indonesia and reviews the Beruk Northeast field as a case history of basement production in the Central Sumatra Basin. The geology of this field is complex, and the production performance of the Beruk Northeast wells has been less predictable than wells in fields producing from the normal Sihapas Group Sandstone reservoirs.

The importance of core recovery can be poor and mud losses are common when drilling fractured basement. Nevertheless our experience in this oilfield indicates that cores must be obtained because they provide the only direct method of observing the fracture network and obtaining fundamental reservoir data.

Cumulative oil production to date from Beruk Northeast is approximately 1.23 million barrels of oil. Although this field is relatively small, the existence of nearby production facilities as the Beruk-Zamrud pipeline encourages exploration and development of fields of this size. Beruk Northeast indicates that Pre-Tertiary basement can not be disregarded as an exploration objective in Southeast Asia. Beruk Northeast also serves as a reminder that whenever feasible, all exploratory wells in Southeast Asia should be drilled into basement.

ACKNOWLEDGEMENTS

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REFERENCES CITED


FIG. 2 LOCATIONS OF INDONESIAN OIL FIELDS PRODUCING FROM PRE-TERTIARY BASEMENT ROCKS
FIG. 4 MAJOR TECTONIC ELEMENTS
(MODIFIED FROM EUBANK + MAKKI, 1981 AND LEE, 1982)
**FIG. 5 STRATIGRAPHIC CHART OF CENTRAL SUMATRA BASIN**

<table>
<thead>
<tr>
<th>M.Y.</th>
<th>AGE</th>
<th>EPOCH</th>
<th>FAUNAL ZONES</th>
<th>LOCAL STAGES</th>
<th>UNITS</th>
<th>LITHOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td></td>
<td>PLEISTOCENE &amp; RECENT</td>
<td></td>
<td></td>
<td>MINAS FM./ALLUVIUM</td>
<td>Gravel, sand and clay</td>
</tr>
<tr>
<td>-5.2</td>
<td></td>
<td>MESSINIAN</td>
<td></td>
<td></td>
<td>PETANI FM.</td>
<td>Greenish gray shale, sandstone and siltstone</td>
</tr>
<tr>
<td>6.6</td>
<td></td>
<td>TORTONIAN</td>
<td></td>
<td></td>
<td></td>
<td>Brownish gray, calcareous shale and siltstone, occasional limestones</td>
</tr>
<tr>
<td>10.3</td>
<td></td>
<td>SERRAVALLIAN</td>
<td></td>
<td></td>
<td></td>
<td>Fine to medium grained sandstones and shale interbeds</td>
</tr>
<tr>
<td>15.5</td>
<td></td>
<td>LANGHIAN</td>
<td></td>
<td></td>
<td></td>
<td>Medium to coarse grained sandstone and minor shale</td>
</tr>
<tr>
<td>16.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gray, calcareous shale with sandstone interbeds and minor limestone</td>
</tr>
<tr>
<td>22.5</td>
<td></td>
<td>BURDIGALIAN</td>
<td></td>
<td></td>
<td></td>
<td>Fine to coarse grained sandstone, conglomeratic</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>AQUI-TANIAN</td>
<td></td>
<td></td>
<td></td>
<td>Red and green variegated claystone and carbonaceous shale, and fine to medium grained sandstone</td>
</tr>
<tr>
<td>65</td>
<td></td>
<td>PALEOGENE</td>
<td></td>
<td></td>
<td>BASEMENT</td>
<td>Greywacke, quartzite, granite, argillite</td>
</tr>
</tbody>
</table>

AFTER: WHITE (1975) AND WONGSOSANTIKO (1976),
TIME SCALE FROM VAIL/MITCHUM (1979),
EUBANK AND MAKKI (1981)
TABLE 1.
COASTAL PLAINS BLOCK WELL DATA
Summary of Basement Core Data with Age Dates

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Basement Lithology</th>
<th>Age Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beruk Northeast No.1</td>
<td>Brecciated NÉTROQUARTZITE, originally a medium-grained, strongly foliated, metamorphic rock</td>
<td>116 ± 2 My. (Late Triassic), by K/Ar.</td>
</tr>
<tr>
<td>Beruk Northeast No.2</td>
<td>Brecciated NÉTROQUARTZITE, originally a medium-grained, strongly foliated, metamorphic rock</td>
<td>123 ± 4 My. (Late Triassic), by K/Ar.</td>
</tr>
<tr>
<td>Beruk Northeast No.3</td>
<td>Brecciated NÉTROQUARTZITE, originally a medium-grained, strongly foliated, metamorphic rock</td>
<td>120 ± 4 My. (Late Triassic), by K/Ar.</td>
</tr>
<tr>
<td>Beruk Northeast No.4</td>
<td>Brecciated NÉTROQUARTZITE, originally a medium-grained, strongly foliated, metamorphic rock</td>
<td>127 ± 4 My. (Late Triassic), by K/Ar.</td>
</tr>
<tr>
<td>Beruk Northeast No.5</td>
<td>Brecciated NÉTROQUARTZITE, originally a medium-grained, strongly foliated, metamorphic rock</td>
<td>134 ± 4 My. (Late Triassic), by K/Ar.</td>
</tr>
<tr>
<td>Pakning No.1</td>
<td>Brecciated NÉTROQUARTZITE, originally a medium-grained, strongly foliated, metamorphic rock</td>
<td>141 ± 4 My. (Late Triassic), by K/Ar.</td>
</tr>
<tr>
<td>Bungu No.1</td>
<td>Cataclastic muscovite GRANITE, originally a coarse-grained rock, which has undergone severe deformation.</td>
<td>148 ± 4 My. (Late Triassic), by K/Ar.</td>
</tr>
<tr>
<td>Pusaka No.1</td>
<td>Cataclastic muscovite GRANITE, originally a coarse-grained rock, which has undergone severe deformation.</td>
<td>156 ± 4 My. (Late Triassic), by K/Ar.</td>
</tr>
<tr>
<td>Idris No.1</td>
<td>Cataclastic muscovite GRANITE, originally a coarse-grained rock, which has undergone severe deformation.</td>
<td>164 ± 4 My. (Late Triassic), by K/Ar.</td>
</tr>
</tbody>
</table>

*Pyritiferous silty SHALE, extremely fine to fine-grained, very low grade metamorphic argillaceous rock, with a well developed cleavage.*

*Brecciated METAQUARTZITE, almost entirely composed of anhedral quartz, small amount of mica, and minor amounts of minor constituents.*

*Muscovite-rich ARagonite.*

*Garnet-muscovite-tourmaline MICROGRANITE.*

*Muscovite-rich hornfelsic ARagonite.*

*Brecciated METAQUARTZITE.*

*Cataclastic muscovite GRANITE, originally a medium-grained igneous rock which has undergone severe deformation.*

*Cataclastic muscovite GRANITE, originally a coarse-grained igneous rock which has undergone severe deformation.*

*Dark grey, silty fractured SHALE, clayey and matrix-supported, with disseminated calcite in fractures.*

*Hydrothermally or diagenetically altered peraluminous GRANITE consisting of quartz, microcline, altered biotite, muscovite and biotite.*

*Radiometric age dating not possible.*
PRE-TERTIARY BASEMENT LITHOLOGIES AND
RADIOMETRIC AGE DATES.
FIGURE 8  SEISMIC PROFILE OVER THE BERUK NORTHEAST FIELD
EAST
BERUK NE-5
GAMMA RAY • LATERLOG

BERUK NE-1
SP • SHORT NORMAL

BERUK NE-3
GAMMA RAY • LATERLOG

BERUK NE-4
GAMMA RAY • LATERLOG

BERUK NE-2
SP • SHORT NORMAL

WEST

FRAC TURED METAQUARTZITE

FRAC TURED METAQUARTZITE

WEATHERED HORNFELSIC ARGILLITE AND GRANITE

WEATHERED AREMACEOUS ARGILLITE

AREMACEOUS ARGILLITE (UNWEATHERED)

HORNFELSIC ARGILLITE AND GRANITE (UNWEATHERED)

SHEARS GROUP

GRANITE

FIG. 10
BERUK NORTHEAST FIELD
STRATIGRAPHIC CROSS SECTION
FIG. 13 COMPOSITE LOG
BERUK NE. No.4
FIG. 15  BERUK NORTHEAST No. 1  
PRODUCTION PERFORMANCE

BARRELS/DAY

10,000

1,000

100

10


GROSS

WATER

OIL