

Exploring in Asia for Oil and Gas in Naturally Fractured and Weathered Basement Reservoirs

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Introduction

Basement rocks are important oil and gas reservoirs in a number of basins in the world including Indonesia (Sumatra, Kalimantan & Java), China, Viet Nam, India, the West Siberia Basin, Middle East (Egypt & Yemen), South America (Venezuela, Brazil & Argentina), USA (California, Texas, Oklahoma & Kansas), and the North Sea (UK West of Shetlands). The reservoirs include fractured and weathered granites, quartzites and metamorphics.

This author has followed this subject closely for over 35 years since being involved in the early 1980's with the development of the Beruk Northeast basement oil pool in Sumatra. He has also been involved with evaluating basement oil discoveries in Angola and Uganda. He hereby shares his knowledge and experience.



Fig 1. Global occurrences of oil & gas in basement reservoirs

Asia Oil & Gas Production

In Asia, oil and gas is produced from basement reservoirs in Indonesia, Viet Nam, China, and India.

This presentation focuses on select basement oil and gas fields in Asia and also reviews a number of exploration opportunities. Also reviewed is “best practices” for exploring and developing basement fields. Although this paper reviews mostly “success stories” there are also failures since basement reservoirs can be very complicated and unpredictable. Accordingly, two basement fields which proved to be economic failures, Dai Hung (Big Bear) in Viet Nam and Beruk Northeast in Central Sumatra are presented.

Viet Nam

The most well-known oil field in Viet Nam is the giant-size Bach Ho (White Tiger) basement oil field. Other basement oil fields include the Dai Hung (Big Bear), Ca Ngu Vang (CNV), Rong (Dragon), Rang Dong, Ruby and Su Ten Den fields with oil reserves ranging from 100 to 400 million barrels of oil.

Bach Ho (White Tiger) Oil Field

This is a giant oil field with estimated reserves of 1.0 to 1.4 billion barrels recoverable. The field was discovered by Mobil in 1975 with oil found in Oligocene sediments draping a basement high. Due to the political situation, Mobil was not able to develop the field and exited from Viet Nam. However, in 1988 VietSovPetro found oil in fractured Precambrian granite basement. Oil production peaked at about 280,000 barrels of oil per day in 2005. By 2009 production was down to 125,000 barrels of oil per day and has continued to decline to 65,000 barrels of oil per day in 2018. The oil production is 95% from the basement reservoirs and 5% from the Oligocene sediments which drape and overly the basement high.

The oil is stored in macrofractures, microfractures, and vuggy pores within the fractures. Matrix porosity within the granite is negligible. Most of the fractures inside basement are at high dip angles of 40 – 75 degrees. Porosity in the fractures is only 2 – 3% but permeabilities are excellent at ten to thousands of millidarcies. Accordingly, flow rates have been measured at up to 14,000 barrels of oil per day per well. The Bach Ho's giant-size reserves are due to presence of abundant fractures and also the oil column being up to 1,500 meter in height.

Dai Hung (Big Bear) Oil Field

A contrast to the success of Bach Ho is given by the development and production history of the Dai Hung (Big Bear) field where oil and gas is hosted in a similar granite/granodiorite matrix (references: Trinh Xuang Cuong & J.K. Warren, 2009). In 1993, Australia's BHP led a consortium that won the bid to develop this field and predicted the field would produce 250,000 barrels of oil per day. By the mid-1990's the field was producing only 25,000 barrels of oil per day and output declined rapidly and in 1997 BHP left the consortium announcing the field was not profitable.

Malaysian state oil company, Petronas took over as operator but failed to raise the output beyond 10,000 – 15,000 barrels of oil per day and left in 1999. In 2000, VietSovPetro, operator of the Bach Ho and Rong fields took over Dai Hung (Big Bear) but was only able to produce about 5,400 barrels of oil per day. Certainly, Dai Hung (Big Bear) illustrates the complexities, uncertainties and challenges which can be associated with basement oil and gas fields. No public information is available regarding the rapid drop in oil production from this field. However, it is rumored that rapid water influx is responsible for this field's disastrous performance.

Ca Ngu Vang (CNV) Oil Field

The CNV field was discovered in 2002 and is the deepest oil-bearing structure in the basin with the top of basement at a depth of 3,700 meters. Operator of the field is SOCO International. The CNV-3 well was the longest measured depth well in Viet Nam at 6,123 meters with over 2,000 meters of basement penetrated in a near-horizontal well bore. The well tested both oil and gas at a rate of 13,040 barrels of oil and gas equivalent.

Indonesia

No major oil fields have been found in basement rocks in Indonesia, however giant-size gas reserves were discovered in the Suban gas field, South Sumatra.

Suban Gas Field, South Sumatra

This field was discovered in 1999 by drilling deep into basement. Approximately 5 TCFG (trillion cubic feet) of gas was discovered in fractured granites. Highly prolific gas wells were drilled on the basis of the wells being highly deviated and oriented perpendicular to the dominant fracture system. The success of Suban has led to further exploration for gas in basement in South Sumatra due to the need for more gas as the Indonesian economy continues to expand. Gas from the Suban field has been pipelined to the huge Duri steam flood project in Central Sumatra as well as to Singapore for electricity power generation. ConocoPhillips is operator of the field.

Kali Berau Dalam Gas Discovery, South Sumatra

In 2019 Repsol announced that their Kali Berau Dalam-2 exploration well had made a major gas discovery in fractured pre-Tertiary basement rocks. This discovery extends the basement gas play 150 kilometers to the northeast of the Suban gas field. The well was reported to have flowed at a rate of 45 million cubic feet of gas per day. Repsol mentioned that the discovery found at least 2 TCFG (trillion cubic feet of gas). On an oil equivalency basis this equals 330 million barrels of oil. For Indonesia, the Kali Berau Dalam discovery is very significant since it is the largest oil or gas discovery in Indonesia in the past 18 years since the Cepu discovery in 2001. Indeed, oil industry analysts have stated that this discovery is one of the ten biggest discoveries in the world in the past year.

Tanjung Oil Field, Kalimantan

The largest oil accumulation in basement in Indonesia is the Tanjung oil field in Kalimantan. This field has produced over 70 million barrels of oil from Eocene sandstones and conglomerates overlying a faulted basement high and it has also produced over 20 million barrels of oil from basement rocks including weathered volcanics, pyroclastics and metasediments.

Beruk Northeast Oil Pool, Central Sumatra

This basement field appeared to be very promising based on the flow rate of 1,680 barrels of oil per day from the discovery well, Beruk North East-1 which was drilled in 1976. The discovery was followed up by 4 development wells which indicated that the basement reservoirs consisted of a variety of rock types and also the field had multiple oil-water contacts. The field produced only 2 million barrels of oil when rapid water influx terminated the life of the field. Some of the development wells barely penetrated the top of basement. Accordingly, a shallow oil-water contact in basement was not penetrated and its existence was not recognized until the field rapidly watered out. As a result, this field proved to be barely commercial and, in all likelihood, lost money.

China

Yaerxia Oil Field

This is an onshore oil field discovered in 1959 and is the first basement "buried hill" field ever discovered in China. The oil is produced from Paleozoic phyllites, slates, and meta-sandstones. The wells are moderately productive with 12 wells producing less than 70 barrels of oil per day, 3 wells producing at 200 barrels of oil per day and 2 wells produce at 875 barrels of oil per day. The wells are not highly productive since the phyllites and slates do not naturally fracture optimally. Similarly, phyllites and slates do not produce good reservoirs when they are weathered.

Dongshenpu Oil Field

This field is located onshore central China and like the Yaerxia oil field is an example of a Chinese "buried hill" basement oil field. The Yaerxia field was discovered in 1983 and the reservoir consists of Precambrian granites, granulites, diabases, and hornblende gneisses. The rocks have no primary porosity but porous reservoirs were developed by weathering and natural fracturing. The discovery well tested at 1,570 barrels of oil per day and subsequent

development drilling has found the oil column to be 400 meters thick. The reserves in this field are estimated at approximately 190 million barrels of oil.

Malaysia

Adang Utara

Malaysia's first basement oil discovery occurred in 2005 with the drilling of Adang Utara-1 in the southern Malay basin, offshore Terengganu. The operator of the well was Petronas, the state oil company of Malaysia. The well was drilled to a total depth of 2,610 meters including 120 vertical meters of basement penetrated. The flow rate of the discovery well is not available; however, 6 appraisal and development wells have been drilled. Flow rates from basement were as low as 159 barrels of oil per day to as high as 2,116 barrels of oil per day. The flow rates are much dependent on the wells optimally intersecting the oil-bearing basement fractures.

Based on a search of public domain information, this author has not been able to find any data on this field's reserves nor rates of production assuming it has been placed on production. A few papers mention that a clastic horizon overlying the basement high is also oil-bearing; however, the split in oil reserves between basement and the clastic unit is not available in the public domain.

India

India is the third largest consumer of crude oil in the world, after USA and China. India's oil and gas demand has significantly outpaced its domestic production.

In India, basement exploration is not a new concept with established oil production from fractured basement in the Borhalla field in the South Assam Shelf in the Assam and Assam Arakan Basin which has been under production for five decades. With the gradual decrease in large, easy-to-find oil pools, there is a shift in the focus of exploration from conventional sedimentary reservoirs to unconventional hydrocarbon accumulations. Basement oil pools fit into the latter category with present efforts for basement exploration being underway in the basins of Cambay, Mumbai High, Cauveray, Krishna-Godvari and the Assam Shelf of India. References: S. Mukherjee (ed.), *Tectonics and Structural Geology: the Indian Context*, 2019, Springer Geology, also S. Mazumber, 2019.

Best Practices for Exploring for and Producing Oil and Gas From Basement Reservoirs

- 1) Production wells should be drilled perpendicular or near-perpendicular to the dominant fracture system. Exploration wells should be drilled highly deviated rather than vertical in order to optimally intersect the dominant fracture system.
- 2) Highly focused 3D seismic such as CBM (Controlled Beam Migration) is needed to define the fracture systems in basement.
- 3) Although coring in fractured basement is difficult and not welcomed by the drilling engineers, nonetheless extensive core is needed to provide critically important information on the lithologies and reservoir parameters. Some of the cores should also be radiometrically age dated in order for the geologists to understand the complexities of the reservoir.
- 4) Development wells should be drilled sufficiently deep to fully drain the reservoir. For example, in the La Paz basement oil field, Venezuela, wells are typically drilled 500 meters into basement. In China's Dongshenpu "buried hill" basement field, the oil column is 400 meters thick and development wells typically are drilled through most of the reservoir.
- 5) Exploration wells should not just "tag" the top of basement since this will not allow for full evaluation of the basement and could result in an important discovery being "left behind". Indeed, the Suban gas field, South Sumatra was not discovered in the mid

1980's by Caltex (Chevron-Texaco) despite a major exploration program since the wells were drilled through the sedimentary section and then merely tagged into basement. The underlying giant basement gas field (5 trillion cubic feet of gas) was subsequently discovered in 1999 by Gulf Canada and Talisman by drilling deep into basement.

- 6) There are a number of cases worldwide, such as the giant-size La Paz field in Venezuela where oil in the basement was discovered much later (30 years) in the life of the field with the attention initially focused on producing oil from the overlying sedimentary reservoirs. Approximately 400 million barrels of oil has been produced from basement. The initial production rates (IP) average 3,600 barrels of oil per day and the maximum IP is 11,500 barrels of oil per day.

A second example of this is the Octongo oil field, Nequen Basin, Argentina which was discovered in 1918 and produced oil from shallow sediments overlying basement. Finally, almost a century later basement was evaluated and now provides recent upside. The basement reservoir consists of Paleozoic granites. The source rock is the Vaca Muerta shales and the oil column is about 450 meters thick. Production in 2015 from basement averaged 3,000 barrels of oil per day and continues to increase and has given a new life to this aging field (reference Velo et al, 2014, AAPG). The La Paz and Octongo fields highlight that operators of fields producing from sediments draped over basement highs should consider drilling a well down into basement. High resolution 3D seismic will help with defining the best location to optimally intersect the fractured or weathered basement.

- 7) Weathered "rotten" granites can also be excellent reservoirs as one can observe in outcrops in tropical areas where heavy rainfall can leach out feldspars and less resistant minerals and leave behind an excellent reservoir. Rocks such as schists and gneisses are less attractive since they are ductile and tend to "smear" and not fracture when subjected to tectonic stress. The high mafic contents of schists also negates the creation of secondary porosity by weathering. Likewise, granites and quartzites are more likely to produce attractive, highly porous "granite wash" sands whereas eroded schists and gneisses do not produce such good reservoirs.

Conclusions

While oil and gas fields in basement are still discovered mostly by accident, there are a few companies who have been especially successful in finding oil in basement which are SOCO International in Viet Nam and Yemen and Hurricane Exploration in the UK's West of Shetlands area. Hurricane's success can be viewed as a "basin revival play" for the North Sea.

The conventional way of thinking, certainly in the past, has been that in exploration programs the top of basement is mostly tight and in oil patch lore was regarded as "tombstone". Indeed, the sands near the top of basement were often described tongue-in-cheek as the "suitcase sands" since that signified that the well was near to total depth and likely a dry hole so it was time for the geologist to pack up his suitcase and go home.

However, this author believes that significant oil and gas fields remain to be found in Asia and worldwide. Unconventional geological thinking and risk-taking has led to many of the world's major oil and gas discoveries and such strategies will reward the explorers searching for oil and gas in basement.

Acknowledgements

Since publishing papers on oil and gas-bearing basement reservoirs beginning in 1984, as detailed below, the author has developed an abiding interest in basement fields. He has made numerous presentations on basement fields at conferences in Singapore, Jakarta, London, Istanbul, Russia, Angola, Nigeria (Lagos & Abuja), Cape Town, and North America (Calgary, Houston & Pittsburgh). In September, 2019 he was a keynote speaker on basement

reservoirs in Kazan, Republic of Tatarstan, Russia at the International Conference on Oil & Gas in Crystalline Basement

Lastly, the reader is referred to one of the first papers published on oil and gas in basement which was by Dr. K. K. Landes et al in 1960 where he stated: "*Commercial oil deposits in basement rocks are not geological "accidents" but are oil accumulations which obey all of the rules of oil sourcing, migration and entrapment; therefore in areas of not too deep basement, oil deposits within basement should be explored with the same professional skill and zeal as accumulations in the overlying sediments*".

Select References

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