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Exploring in North and South America for Oil and Gas in Naturally Fractured Basement Reservoirs

Tako Koning
Senior Geologist/ Consultant

Introduction

Basement rocks are important oil and gas reservoirs in a number of basins in the world including Asia (Indonesia, China, Viet Nam, & India), Russia, Middle East (Yemen), Africa (Algeria, Libya & Egypt), South America (Venezuela & Brazil), USA (California, Kansas, Oklahoma & Texas), and the North Sea (UK West of Shetlands & Norway). The basement reservoirs include fractured and weathered granites, quartzites, metamorphics and volcanics.

The basement oil and gas play has intensified in the past decade with significant basement discoveries in the United Kingdom (Lancaster and Lincoln oil fields), Norway (Rolvsnes oil field), basement oil discoveries in Chad, Argentina and a major gas discovery in basement in 2019 in Indonesia.

This author has followed this subject closely for almost forty years since being involved in 1982 with the development of the Beruk Northeast basement oil pool in Indonesia. He has also been involved with evaluating basement oil discoveries in Angola and Uganda. He hereby shares his knowledge and experience.

This poster paper provides a technical review of basement oil and gas fields in North and South America.

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

Globally the biggest oil and gas fields among the basement fields occur within basement which is heavily naturally fractured. The opinion of this author is that the best rock types are fractured quartzites or granites since they are brittle and thus fracture optimally (Koning, 2019). Fractured gneisses are poorer reservoirs since they can be massive, dense or slabby with open fractures parallel to the direction of foliation. Rocks such as gneisses and schists are ductile and tend to "smear" and not fracture when subjected to tectonic stress. Phyllites and slates are the least attractive since such rocks are not brittle, rather they are thinly bedded, fissile and ductile and fracture poorly.

Weathered granitic basement can also be an excellent reservoir such as in the giant Auguila-Naafora oil field in Libya. Prolific oil pools producing from weathered basement reservoirs also occur in China and India.

The following is the preference scale for basement reservoir rock types:

- Fractured quartzites……..*Most preferred rock type*
- Fractured granites
- Fractured carbonates
- Weathered granites
- Fractured gneisses
- Weathered gneisses
- Fractured schists
- Weathered schists…….*Least preferred rock type*

Oil and gas fields in basement require the same geological criteria as conventional oil and gas fields which includes reservoir rocks (fractured or weathered basement), oil & gas source rocks adjacent to or overlying basement, structural closure, and cap rocks which seal off the basement reservoirs.

North America

CANADA

Canada is the world's fourth largest oil producer with production of 4.5 million barrels of oil per day. The world's top oil producer is the USA with production of 12.6 million barrels of oil per day, followed by Saudi Arabia at 11.8 million barrels of oil per day, followed by Russia at 11.4 million barrels of oil per day.

In view of Canada having such prolific petroleum geology, it is anomalous that there is no production from basement anywhere in Canada. This may be attributable to the absence in Canada of good oil or gas source rocks overlying basement which would feed oil or gas into basement. In addition, in Canada the basement oil and gas play is poorly understood thus there has never been a deliberate, highly-focused effort to explore for oil and gas in basement.

California

The state of California produces currently about 0.5 million barrels of oil per day. This production is almost entirely from Tertiary Miocene age sandstones and conglomerates except for the following fields which produce from basement reservoirs:

1.) Playa de Rey Field, Santa Monica area. Production from fractured Jurassic schists.
2.) Santa Maria field, Santa Barbara area. Production from fractured Jurassic sandstone basement.
3.) Willmington Field, Long Beach area. Production of 22 million barrels of oil from fractured Jurassic schists.

4.) Edison Field, Bakersfield area. Production of 20 million barrels of oil from fractured Jurassic schists.
5.) El Segundo Field, western Los Angeles area. Reservoir is fractured Jurassic schist in the west half of the field and fractured Jurassic schist conglomerate in the eastern half with oil tested up to 4,500 barrels of oil per day from the basement at a depth of about 2,150 meters.

Kansas
Oil is produced in the state of Kansas from the top of fractured Precambrian quartzites which occur in buried hills. The oil source rocks are the overlying Pennsylvanian age shales which also form the cap rock. Kansas has approximately 10 small pools which produced about 150,000 barrels of oil per well. An example is the Orth pool which produced about 1 million barrels of oil from 15 wells.

The production of oil from these small pools is commercially viable since the shallow depth of the basement reservoirs results in modest drilling costs. The area where these basement pools occur is an area with extensive oil production from conventional oil fields and related existing oil production infrastructure including pipelines and oil gathering stations. Accordingly, connecting the basement wells into the existing oil infrastructure is not expensive.

Oklahoma
The 15-kilometer diameter Ames structure in northwestern Oklahoma is a meteor impact structure created when a meteor struck in Middle Ordovician time. Oil and gas production is obtained from the brecciated Precambrian granite as well as from the overlying Cambro-Ordovician Arbuckle dolomite.

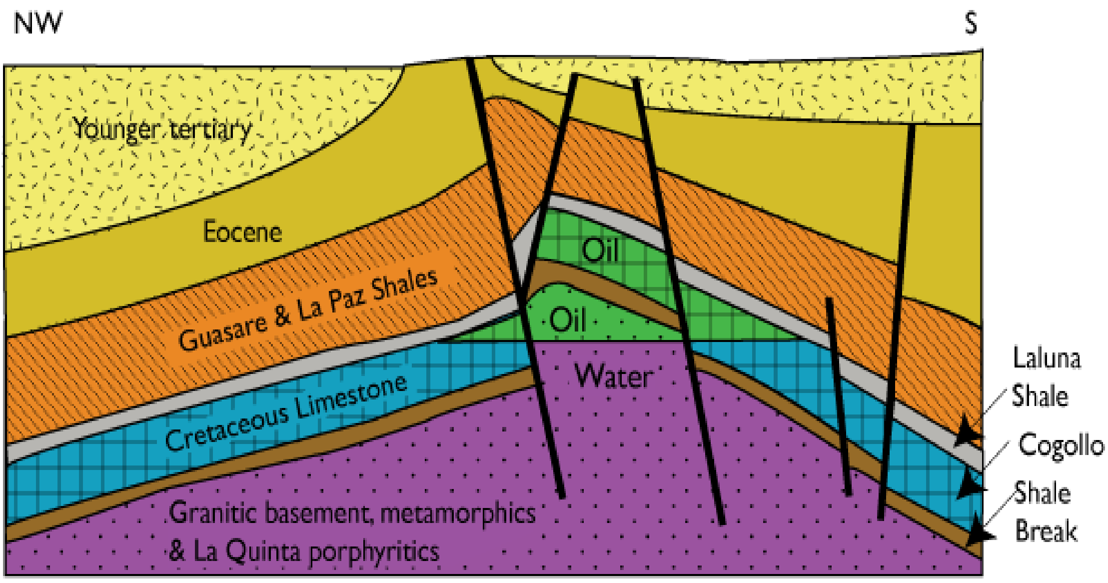
Texas
In northern Texas in the Panhandle - Hugoton area, oil is produced in the Anadarko Basin from fractured Precambrian rocks (Manwaring & Weimer, 1986). These oil pools, including the Apco Field, consist of basement highs which resulted from structural deformation and paleo-weathering. The oil is believed to have migrated from the Devonian Woodford Shale into basement along ubiquitous fractures, and accumulated in open fracture zones associated with faults.

The depth of production averages 1,060 meters. Basement oil production ranges from as low as 1 barrel of oil per day to as high as 700 barrels of oil per day. Drilling within a fault zone does not assure basement production. Other geological factors are equally important to basement oil accumulations and production which includes fault orientation, fracture type, mineralization within the fractures, degree of weathering, basement subcrop elevation, lithology, fault intensity, and proximity to fault-associated fracture zones. Proper drilling methods into basement is equally important as well as appropriate treatment of the basement reservoir during the completion of the well.

South America
Venezuela
The giant-size La Paz oil field is located in the Maracaibo Basin in the interior of Venezuela. The field was discovered in 1944 and up to the year of 1992 has produced 830 million barrels of oil from the La Luna limestones and 325 million barrels from the underlying fractured basement reservoir (Landes et al, 1960, Talukdar et al, 1994, Koning, 2003, Koning, 2018). After the discovery of the field, due to the strong production performance of the La Luna reservoir, the geoscientists and reservoir engineers speculated that the reservoir was

obtaining production support from a deeper reservoir. Accordingly, 30 years after the discovery of the field a well was drilled into the underlying basement and discovered the La Paz basement field.

The discovery well produced at a rate of 1,000 barrels of oil per day from the La Lunda limestone. Basement wells have had initial production rates of up to 11,500 barrels of oil per day but the average initial production rate is 3,500 barrels of oil per day.



Vertical section through the **La Paz field, onshore Venezuala**. Aprox 830 MMbls oil produced from low porosity Cretaceous limestones and 325 MMbls produced from fractured granite basement. Maximum IP of basement wells was 11,500 BOPD average IP of 3,600 BOPD. Average penetration into basement is 500 meters (1,700 feet). Source rock is the Laluna shale which is also the cap rock for the limestone reservoir.

From: Landes et al, 1960, Talukdar & Marcano, 1994, modified by Koning, 2000.

Brazil
The only field in Brazil which has produced oil or gas from basement is the Carmopolis Field in the onshore Sergipe sub-basin. This field has produced oil from Cretaceous sandstones and the underlying basement. The depths of all reservoirs are very shallow, ranging from depths of 400 to 800 meters. The oil gravity ranges from 24 to 30.5 degrees API. Approximately 85% of the oil production is from the overlying sediments and 15% from basement. Approximately 35 million barrels of oil has been produced from basement.

Argentina
The Octogono Field is the only field in Argentina to have produced oil or gas from basement. This field was discovered in 1918 in the onshore Neuquen basin and produced oil from the sediments overlying basement. Deeper drilling almost a century later focused on the basement and resulted in oil discovered in basement which in 2015 provided oil production of 3,000 barrels per day (Velo, 2014).

The primary source rock in the Neuquen basin is the organically-rich Vaca Muerta Formation (Spanish for Dead Cow) which is of Late Jurassic to Early Cretaceous in age. In the Octogono Field, the primary basement lithology is Paleozoic granite. All permeability and storage has resulted from fracturing and alteration. Fracturing in basement resulted from the uplift of basement more than 1,000 meters above the ground rocks. Six alteration zones corresponding to differential weathering has been identified.

The recovery factor in basement is estimated at 25% due to expansion of a 300 meters gas cap. The oil column in basement is 300 meters. The discovery of oil in basement and the ongoing development of the basement reservoir has given new life to the Octogono Field.

BEST PRACTICES FOR DISCOVERING AND PRODUCING OIL FROM FRACTURED & WEATHERED BASEMENT RESERVOIRS

1) Exploration wells should be drilled highly deviated rather than vertical in order to optimally intersect the dominant fracture system. Production wells should be drilled perpendicular or near-perpendicular to the dominant fracture system.
2) Highly focused 3 dimensional (3D) seismic such as CGG – Veritas' CBM (Controlled Beam Migration) is needed to define the fracture systems in basement oil & gas fields.
3) 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 Canada's Talisman Energy 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. A second example of this is the Octogono oil field, Neuquen Basin, Argentina which was discovered in 1918 and produced oil from shallow sediments overlying basement. Finally, almost a century later, basement was drilled and evaluated and now provides reserves and production upside. 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. The La Paz and Octogono fields highlight that operators of oil & gas fields producing from sediments draped over basement highs should consider drilling a well down into the 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. The high mafic minerals in schists, phyllites and slates 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.
8) Geologists, geophysicists, reservoir engineers, and economists must study proven analogues of basement oil and gas fields worldwide in order to fully understand any basement discoveries they are attempting to develop. They must develop an

understanding of why some basement fields are highly successful and why others are failures. This knowledge must then be applied to their ongoing basement oil and gas projects.

CONCLUSIONS

In the past, oil and gas fields in basement were discovered mostly by accident. The conventional way of thinking in the past was that basement is mostly tight and did not warrant exploring. However, today there are a few companies who are highly basement-focused and have been especially successful in finding oil in basement. They are SOCO International in Viet Nam & Yemen and Hurricane Exploration in the United Kingdom's West of Shetlands area. Hurricane's recent successes can be viewed as a "basin revival play" for the mature North Sea basin.

Basement reservoirs are very unusual in comparison to conventional sedimentary rock oil and gas reservoirs since the basement reservoirs are in crystalline rocks. Accordingly, to successfully work with basement rocks, a special "mind set" is required which is open to all of the complexities associated with crystalline rocks.

This author believes that significant oil and gas fields remain to be found in the Americas 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.

Understanding basement reservoirs is not only important for oil and gas, but this knowledge is also very relevant to the need to reduce the world's Green House Gases (GHG). Carbon dioxide (CO2) can be captured an injected into fractured or weathered basement and thereby can be safely and permanently stored.

Also, a commodity which is increasingly in short supply in the world is helium. Economic helium is derived from the radioactive decay of uranium and thorium in basement rocks and granite washes. In Canada's province of Saskatchewan, significant programs have commenced exploring for helium in basement reservoirs.

Lastly, the reader is referred to one of the first papers published on oil and gas in basement which was the classic paper by K. K. Landes et al in 1960 in which it was states: "*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*".

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