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Exploring in South America for Oil and Gas in Naturally Fractured 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 Asia (Indonesia, China, Viet Nam, & India), Russia, Middle East (Yemen), Africa (Libya, Egypt & Chad), South America (Venezuela & Brazil), USA (California, Kansas, Oklahoma and Texas), and the North Sea (Norway). The basement reservoirs include fractured and weathered granites, quartzites, metamorphics and volcanics.

This author has followed this subject closely for over 40 years since being involved in 1982 with the development of the Beruk Northeast basement oil pool in Central Sumatra, Indonesia. He has also been involved with evaluating basement oil discoveries in Angola and Uganda. He hereby shares his knowledge and experience.

In South America, oil has been produced in only Venezuela, Brazil and Argentina. This author believes that the basement oil and gas play is much under-evaluated and misunderstood.

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

Venezuela: La Paz Oil Field

The La Paz oil field is one of the most famous and well-documented fractured reservoirs in the world. La Paz is located in the Maracaibo Basin west of Lake Maracaibo, Venezuela. The field was discovered by Shell Oil in 1922 and up to the year of 1992 had produced 830 million barrels of oil from fractured Cretaceous limestones and from the underlying fractured basement (Landes et al, 1960, Talukdar et al, 1994, Koning, 2003, Koning, 2014). The field's peak production was 160,000 barrels of oil per day (Nelson et al, 2000).

For geoscientist and engineers who are interested in basement reservoirs, the development of La Paz is very relevant. The discovery of oil in the underlying basement was not made until 1953, 31 years after the discovery of oil in the overlying sedimentary formations. After the discovery of the oil in the Cretaceous limestones, due to the very strong oil production performance of the reservoir, the reservoir engineers and geoscientists carried out extensive materials balance studies and predicted that the reservoir was obtaining production support from a deeper reservoir. Accordingly, in 1953, 31 years after the discovery of La Paz, well P-86 was drilled into the underlying basement and discovered oil in the basement. P-86 was drilled to a depth of 2,710 meters (8,890 feet) and penetrated 332 meters (1,089 feet) of basement and was tested at 3,900 barrels of oil per day. Up-to-date data is not available on the oil production from La Paz or any of Venezuela's oil and gas fields. However, by 1993 approximately 246 million barrels of oil had been produced from the basement in La Paz.

Very relevant for those involved with exploring for and producing oil or gas from basement reservoirs is the work done by a multidisciplinary team led by R.A. Nelson. Their analysis of the La Paz field (Nelson et al, 2000) indicated that the higher oil flow rates is related to fracture swarms surrounding numerous faults within the field that were developed during the strike-slip origin of the current structure.

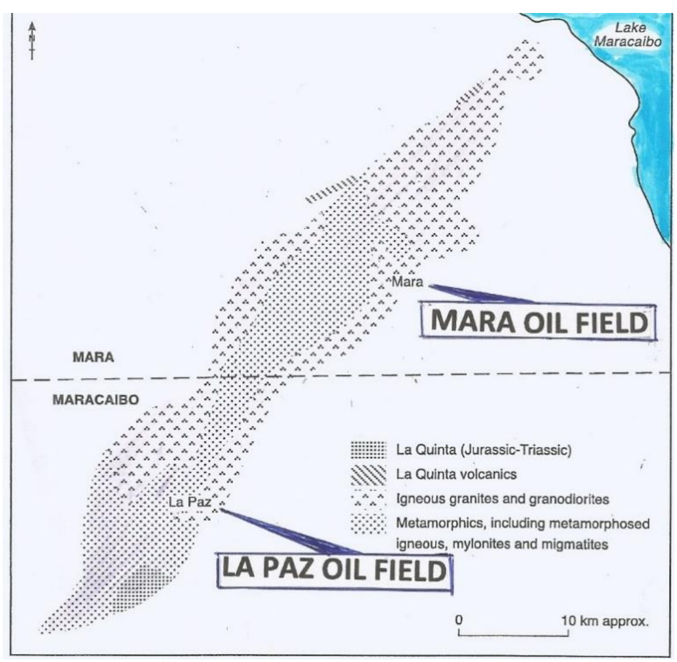

Fig 2. Summary map showing the main basement lithologies of the La Paz and Mara oil fields, Venezuela. From: Landes et al, 1960.

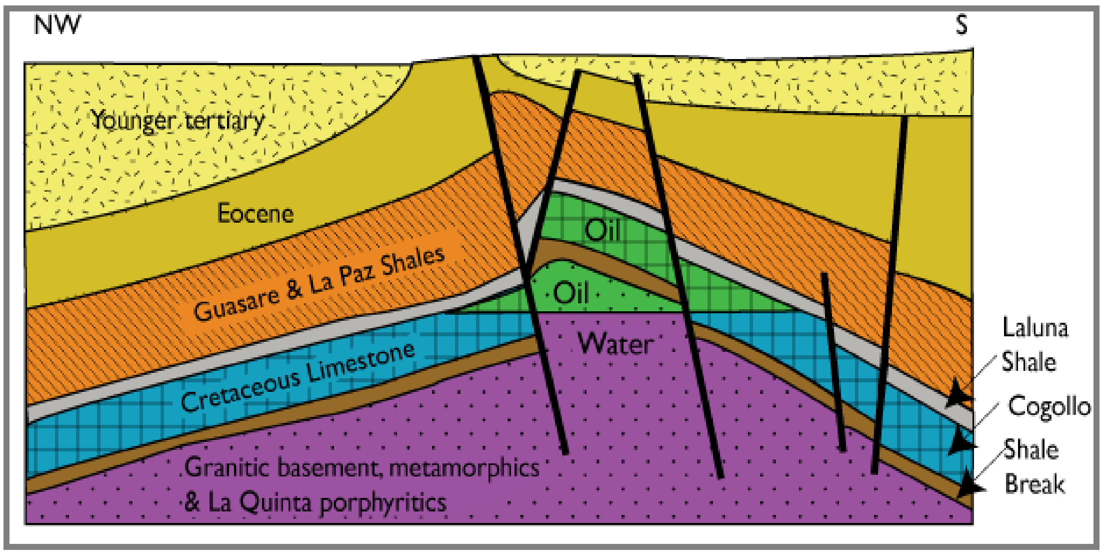

Fig 3. Structural cross-section through the La Paz oil field. The fractured basement reservoir is in pressure communication with the overlying fractured limestones hence a common oil-water contact is in the field. From: Smith, 1956; Landes et al, 1960, Talukdar et al, 1994; modified by Koning, 2000; Koning, 2003.

Venezuela: Mara Oil Field

The Mara field was discovered in 1945 by Shell and is located 12 km to the northeast of La Paz. The two fields are separated by a structural saddle and also tight limestones. The initial exploration found oil in fractured Cretaceous La Luna limestones. However, in 1953, Mara's first basement well was drilled and penetrated 332 meters (1,090 feet) of basement, consisting of fractured granites and metamorphics, and tested 6,500 barrels of oil per day. The strongest oil producer in basement in Mara is DM-12 which had an IP (initial production rate) of 17,000 barrels of oil per day from basement. Mara has an estimated ultimate potential recovery of 525 million barrels of oil from fractured granitic basement as well as fractured Cretaceous limestones (Young, 1993). By 1955, basement oil production from La Paz and Mara amounted to 80,000 barrels of oil per day (Smith, 1956).

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 Exploring For and Producing Oil and Gas From 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 various operators since the wells were drilled through the sedimentary section and then merely tagged into basement. The underlying giant basement gas field (6 trillion cubic feet of gas) was subsequently discovered in 1991 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.

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. 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 Asia, Africa, 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 provinces of Saskatchewan and Alberta, 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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Additional Information

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