Exploring in the USA and Canada 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 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), Fig.1. The basement reservoirs include fractured and weathered granites, quartzites, metamorphics, and meta-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.

Figure 1. Global distribution of oil & gas fields in basement reservoirs

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 naturally fracture poorly.

Weathered granitic basement can also be an excellent reservoir such as in the Auguila-Naafora oil field in Libya.

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 or weathered basalts
- Fractured schists
- Weathered schists………*Least preferred rock type*

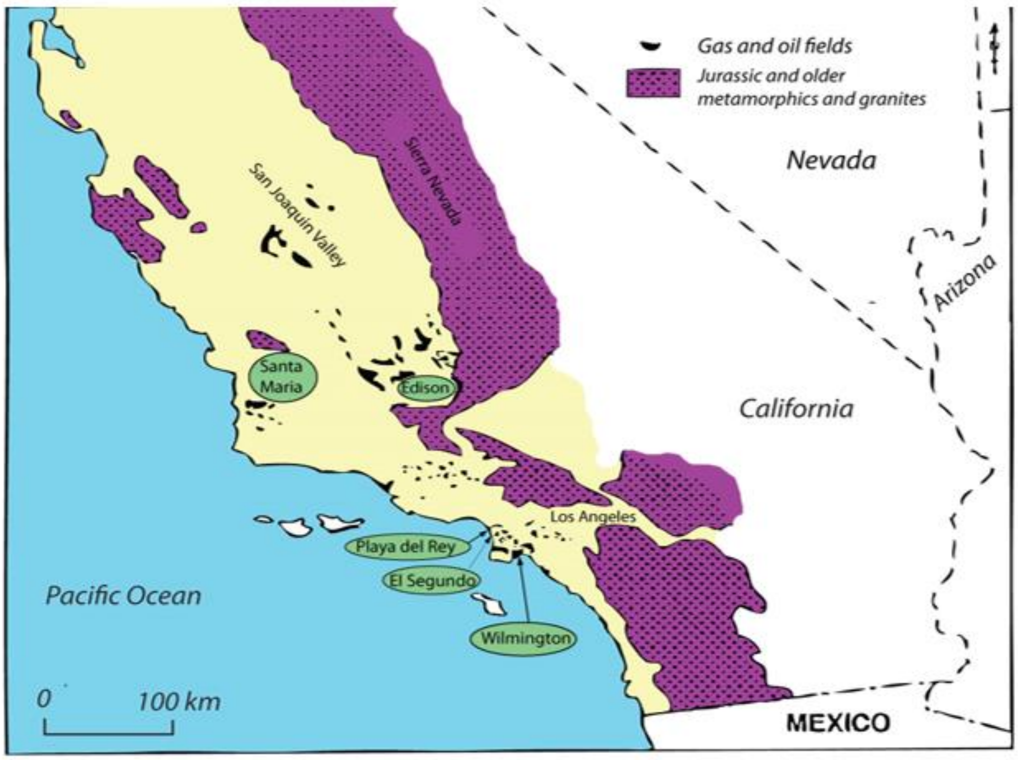
Oil and gas fields in basement require the same geological criteria as conventional oil and gas fields which includes reservoir rocks (naturally fractured or weathered basement), oil & gas source rocks adjacent to or overlying basement, oil and gas migration paths, structural closure, and cap rocks which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

California

The state of California produces currently about 500,000 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.



Map showing the main Californian gas and oil wells of El Segundo, Santa Maria, Wilmington, Playa del Ray, and Edison. The fields circled in green produce oil from basement reservoirs. (Landes et al. 1960).

Fig 2. Oil and gas fields in California with oil fields producing from basement circled in green.

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 feet. 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.

Canada

Canada is the world's fourth largest oil producer with production of 4.7 million barrels of oil per day. The world's top oil producer is the USA with average production in 2020 of 11.0 million barrels of oil per day, followed by Russia at 10.8 million barrels of oil per day, followed by Saudi Arabia at 10.4 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. In contrast, in the USA and Russia there is production of oil from basement reservoirs which may be due to the geology being more favorable for oil and gas in basement. However, this may also be because the basement oil and gas play is better understood in the USA and Russia. Also, in

Saudi Arabia there is no oil or gas production from basement for perhaps the same reason as Canada which has no oil or gas production from basement.

This author is aware of only one instance in Canada when exploration drilling was carried to deliberately to explore deep into basement. This was known as the Hunt well, named after its promoter, Charles Warren Hunt, which was drilled in 1994 deep into basement in a location just west of Fort McMurray. This well was named AOC Granite 7-32-89-10W4 and penetrated Precambrian granite basement at a shallow depth of 541m (1,775 ft). The well reached a total depth of 2,363m (7,753 ft) after drilling through 1,822m (5,978 ft) of granite (Majorowiz et al, 2014). In this presentation the outcome of this well will be reviewed in more detail. The well was re-entered and deepened in 2003 to reach to the FTD of 2,363m. More recent logging was carried out in 2011 to provide temperatures and geothermal gradients to determine the area's potential for geothermal energy. This was carried out a consortium of Canadian researchers at the University of Alberta and from German academic institutions.

Fig. 3. Precambrian granite core from the deepest section of the Hunt well below 2300m (7,546 ft). The diameter of the core is 10cm (4 inches).

Best Practices for Exploring for and Producing Oil an 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 giant-size 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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