Oil and gas production from basement reservoirs: examples from Indonesia, USA and Venezuela

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Abstract: Basement rocks are important oil and gas reservoirs in various areas of the world. Such reservoirs include fractured or weathered granites, quartzites, or metamorphics. In South America, basement reservoirs occur in Venezuela and Brazil. In North Africa, basement oil and gas production occurs in Morocco, Libya, Algeria and Egypt. Significant basement reservoirs occur in the West Siberia basin as well as in China. In the USA, basement-derived oil production occurs in a number of areas, including California (Wilmington and Edison fields), Kansas (El Dorado and Orth fields) and Texas (Apco field). In Southeast Asia, basement reservoirs are the main contributor of oil production in Vietnam. In Indonesia, to date oil and gas production from basement rocks has been minimal. However, the recent large gas discovery in pre-Tertiary fractured granites in southern Sumatra has led to a focusing of exploration in Indonesia for basement reservoirs.

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 rock (regardless of age) which is unconformably overlain by a sedimentary sequence. Oil or gas may have migrated into older porous metamorphic or igneous rocks, thereby forming a basement reservoir. However, in some basins such as the Central Sumatra basin, the basement rocks may be partially or completely unmetamorphosed. Therefore, the most appropriate definition of 'basement' is that of Landes *et al.* (1960) which stated: 'the only major difference between basement rock and the overlying sedimentary rock oil deposits is that in the former case the original oil-yielding formation (source rock) cannot 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 commonly accepted definitions of basement rocks in that area. Further exploration may indeed prove the existence of hydrocarbon source rocks located stratigraphically within rocks previously regarded as basement. Accordingly, the explorationists' definition of basement rocks cannot be rigid but must be responsive to new geological ideas and data.

Indonesia

Central Sumatra

Oil and gas production from pre-Tertiary basement rocks is rare within the Tertiary back arc (foreland) basins of western Indonesia. The Beruk Northeast field (Fig. 1) is the only field in the prolific Central Sumatra basin that produces from basement (Koning & Darmono 1984). The field was discovered in 1976 by the drilling of Beruk Northeast No. 1 which tested 1680 BOPD from fractured basement quartzites (Fig. 2). Approximately 2 million barrels of oil have been produced from quartzites, weathered argillites and weathered granite. The basement rocks have K–Ar radiometric age dates varying from Early Permian to Early Cretaceous, indicating a complex pre-Tertiary geological history. The Beruk Northeast field presents challenging production problems due to the great variability in reservoir rocks, the presence of at least four separate oil–water contacts, and a possible unrecognized water-bearing fracture system.

Southern Sumatra

Exploration targeted for basement hydrocarbons has met with recent success in southern Sumatra, where operator Gulf Indonesia has reported the significant Suban gas discovery (Fig. 1). Three wells drilled in 1999 in the Suban field have defined a gas pool located within fractured pre-Tertiary granites. Gas flow rates of 26 million cubic feet of gas per day were obtained from the Durian Mabok-2 well. Test data combined with seismic mapping indicates a gas pool with a minimum gas column of 500 m covering an area of at least 72 km^2 (Gulf Indonesia 1999; Koning 2000). Reserves are estimated at approximately 5 trillion cubic feet of gas. On an oil equivalency basis, using 1000 cubic feet of gas to 1 barrel of oil, this field has oil equivalent reserves of 500 million barrels which places it in

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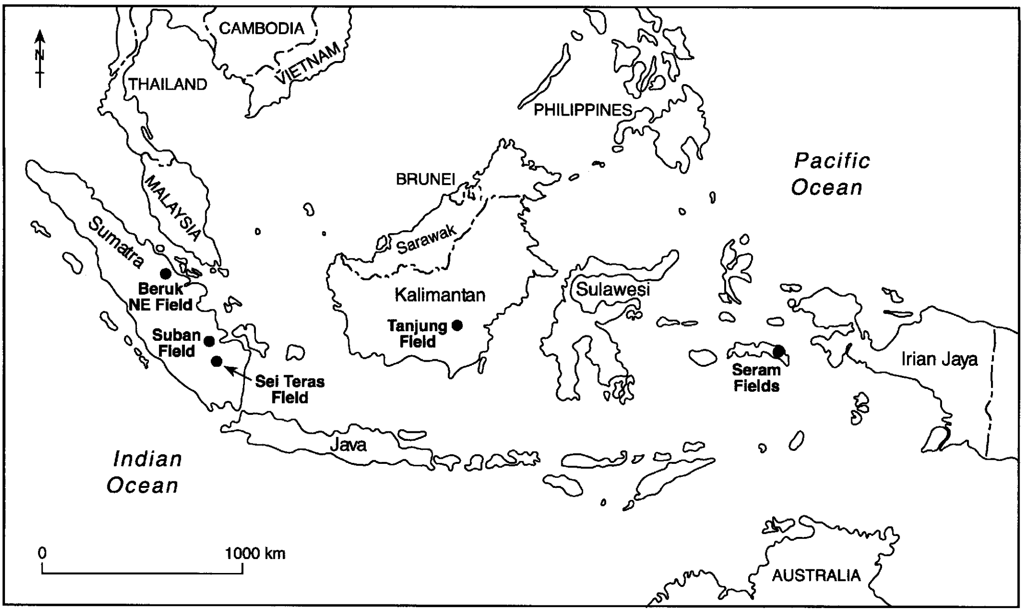

Fig. 1. Locations of Indonesian oil fields producing from pre-Tertiary basement rocks.

the ranks of a 'giant' oil field (AAPG definition of a giant oil field is one with reserves >0.5 billion barrels of oil). Likely markets for the gas include the Duri steam flood project in central Sumatra as well as power generation projects in Singapore.

The area where the Suban field was discovered was previously subjected to a number of exploration campaigns by various operators. The search was for oil in structural highs in the Tertiary Talang Akar and Batu Raja formations. A number of wells 'tagged' into basement in order to tie the top of basement into seismic data. None of these wells penetrated sufficiently deep into basement to discover the giant Suban gas field until Gulf discovered the field in 1999.

Kalimantan

The Tanjung field in the Barito basin, southern Kalimantan, was discovered in 1938 and has produced over 21 million barrels of oil from pre-Tertiary basement rocks (Figs 3, 4 and 5). Oil occurs in volcanics, pyroclastics and metamorphosed sandstones and claystones which are locally deeply weathered and fractured. A general structural section through the oil field is shown in Figure 3.

The Beruk Northeast and Tanjung fields share many similarities. For example, both fields occur within faulted anticlines. The overlying thickness of Tertiary sediments in both fields is less than 2000 m. The likely oil source rocks for these fields are the adjacent and deeper Tertiary shales. The Beruk Northeast, Tanjung and Suban fields indicate that pre-Tertiary basement is a valid oil exploration objective in the Tertiary basins in western Indonesia and that, whenever feasible, exploration wells in these basins should be drilled into basement.

USA

Kansas

In Kansas, oil is produced from Precambrian basement rocks in the central Kansas uplift (Fig. 6). The Precambrian rocks include quartzite, schist, gneiss and granite; however, fractured quartzite is the reservoir rock most often penetrated since it occurs on the summits of many buried Precambrian hills (Landes *et al.* 1960 and Fig. 7). Basement oil pools include the Orth, Ringwald, Kraft-Prusa, Beaver, Bloomer, Trapp, Eveleigh and Silica fields. The source rocks are flanking Cambro-Ordovician shales or overlying Pennsylvanian shales. Production from fields such as the Orth and Ringwald fields is relatively low at production rates varying between 120 and 190 BOPD.

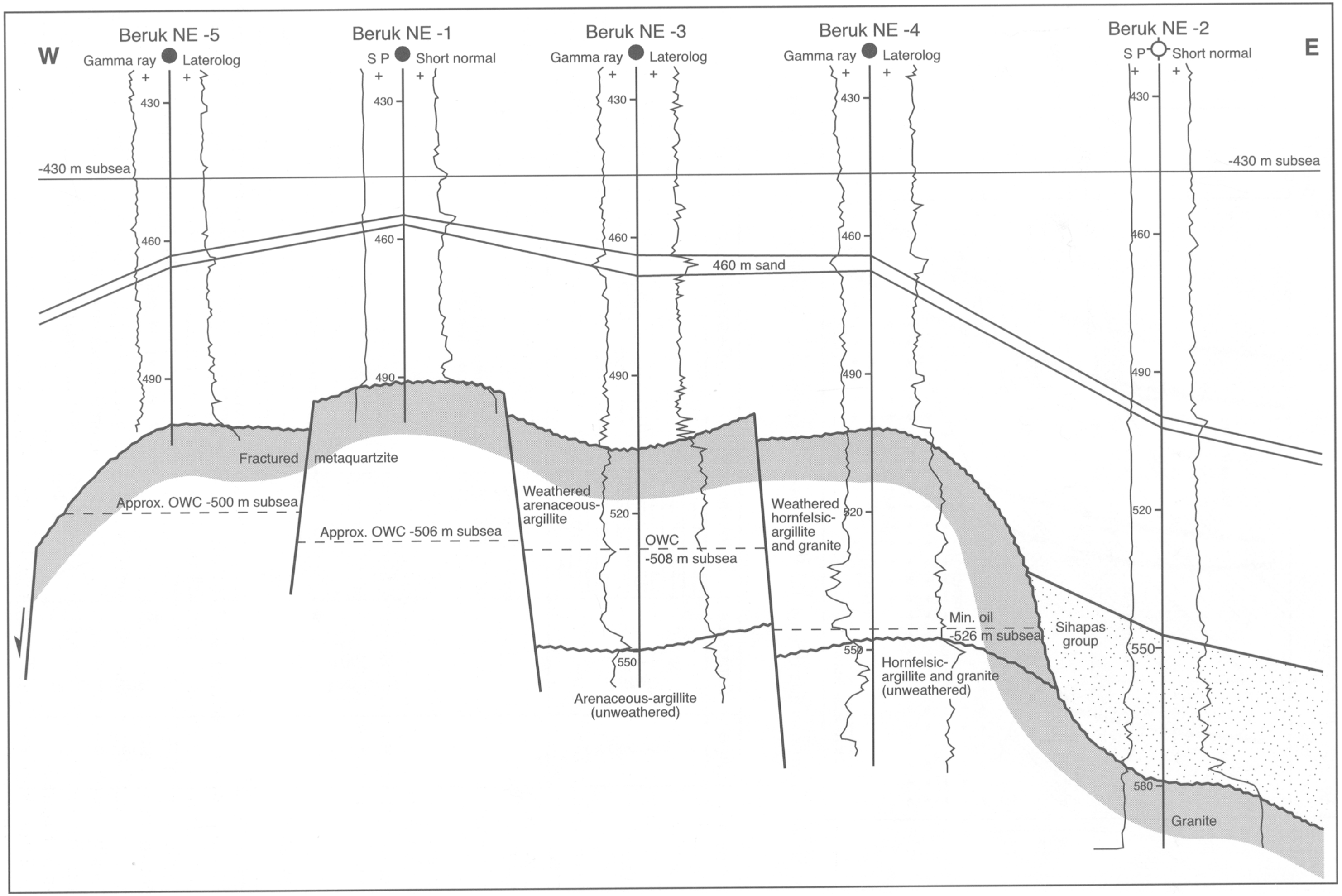

Fig. 2. Structural cross-section through the Beruk northeast field, Sumatra. (Koning and Darmono, 1984).

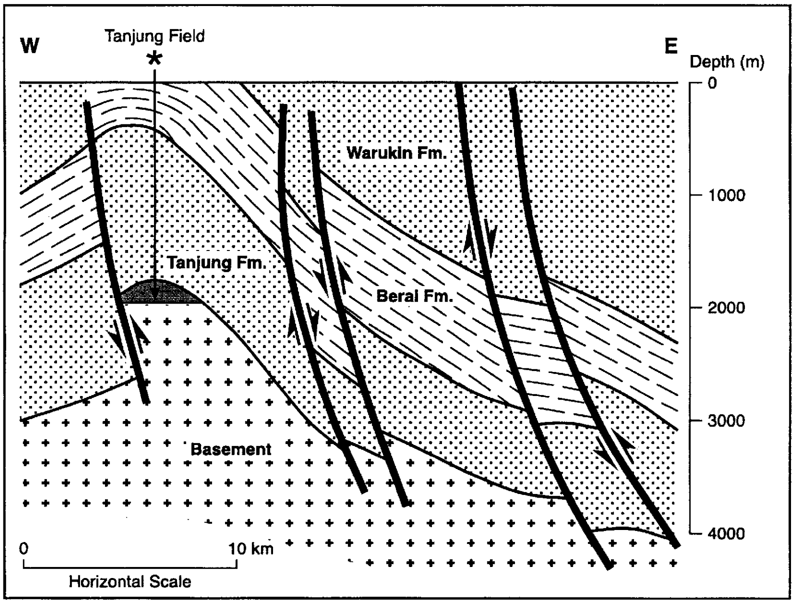

Fig. 3. Structural cross-section through the Barito basin (Tanjung area), Kalimantan (Koning, 2000).

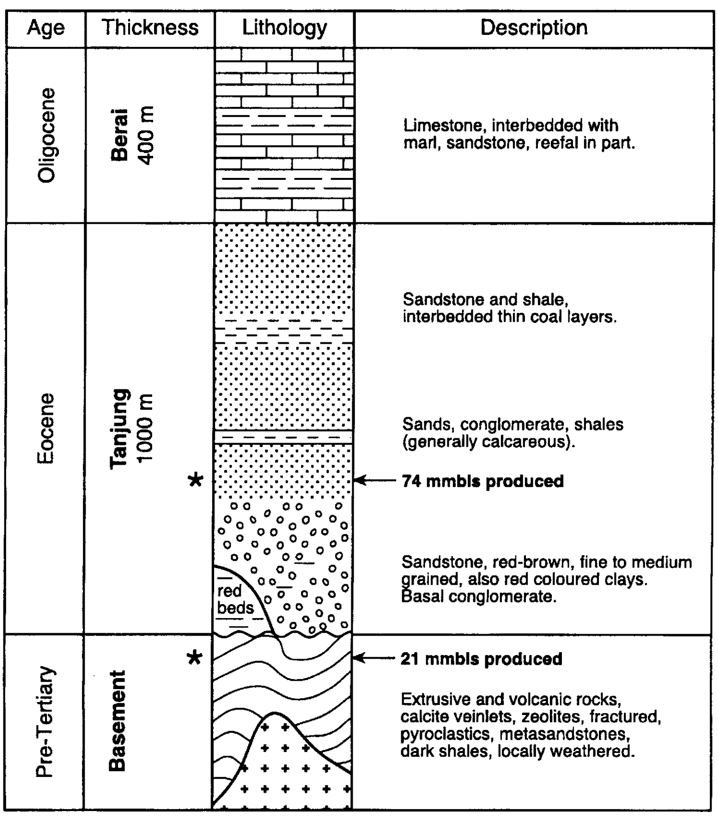

Fig. 4. The general stratigraphy of the Tanjung field, Kalamantan (Koning, 2000).

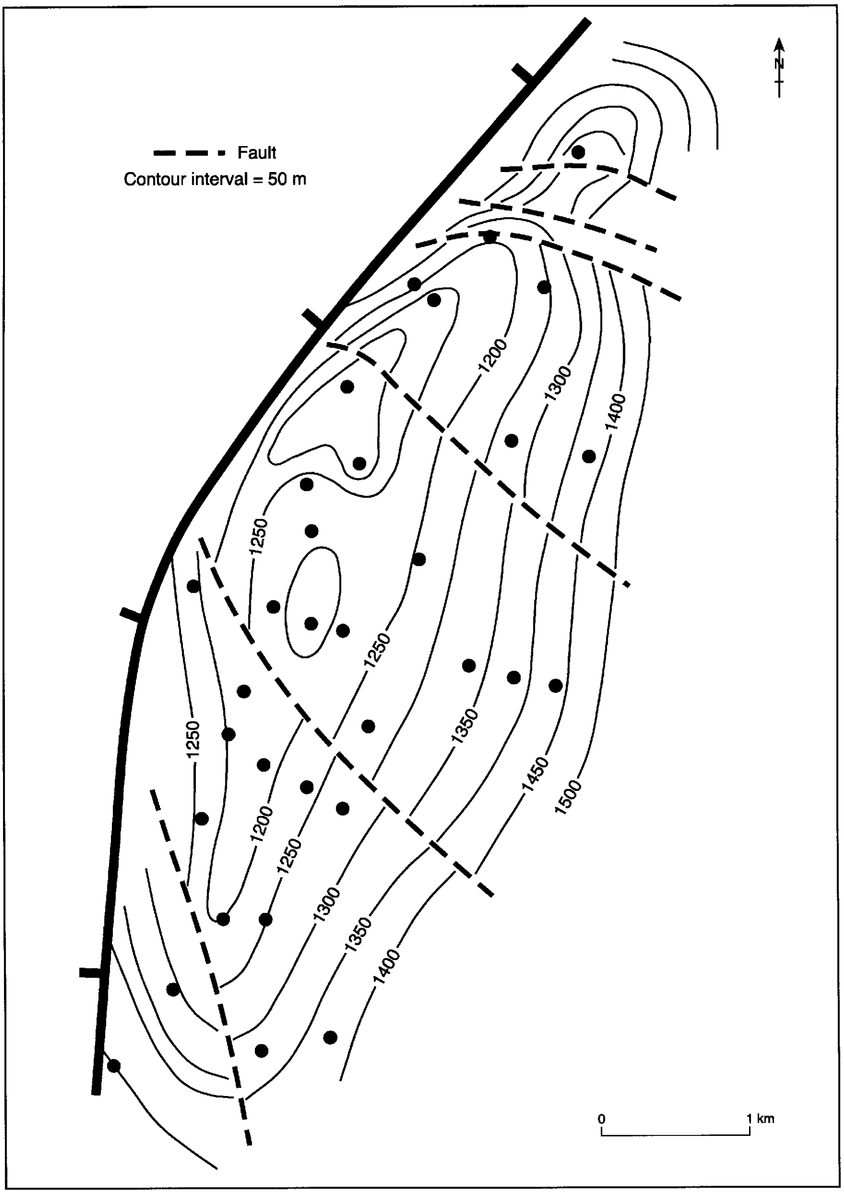

Fig. 5. Structure on top of basement, Tanjung field, Kalamantan (Koning, 2000).

California

In California, oil is produced from basement consisting of fractured Jurassic schists. Fields which contain basement reservoirs include the Playa del Rey, El Segundo, Santa Maria, Wilmington and Edison fields (Fig. 8). Relatively few wells produce from basement rocks alone; most are multiple completions in both the basement schist and overlying schist conglomerate and Tertiary sandstones. The majority of the oil-producing schists are in a relatively high position and have usually undergone weathering and erosion, thus increasing the porosity (Landes *et al.* 1960). The wells in the Edison field had an average production rate of about 1,000 BOPD and cumulative production in the field has exceeded 20 million barrels of oil. The Wilmington field has produced more than 22 million barrels of oil from basement with rates

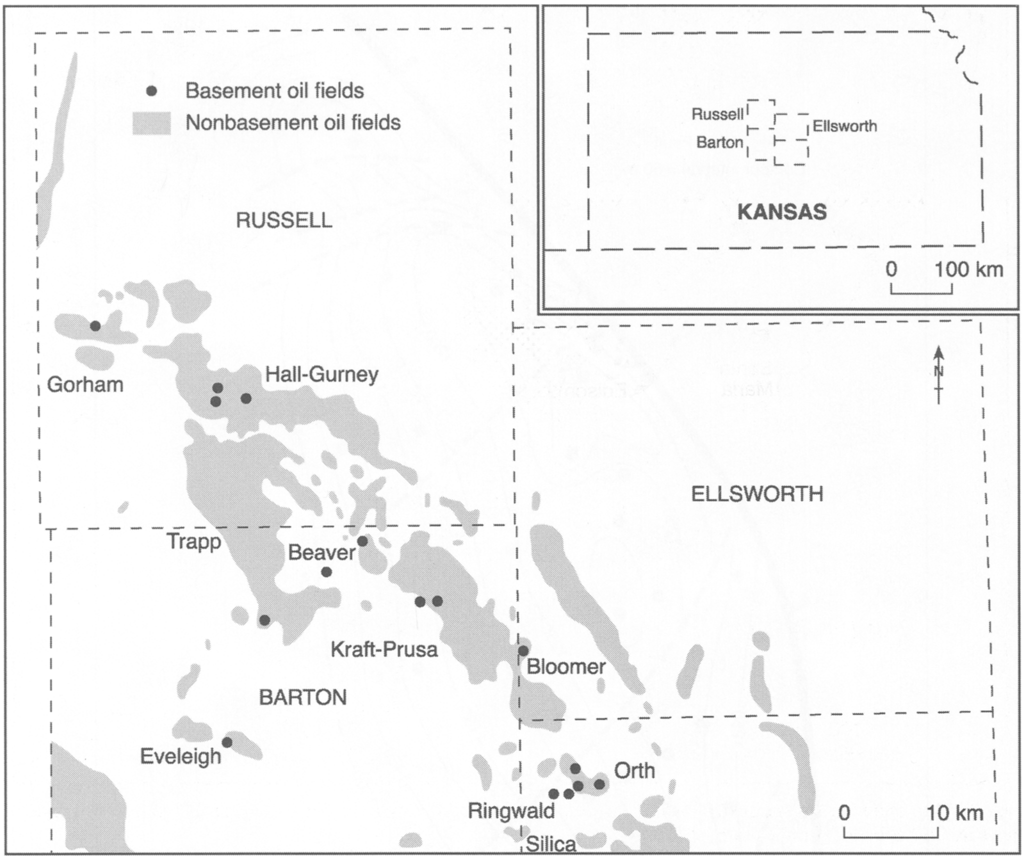

Fig. 6. Map showing the location of the Kansas basement oil fields. (Landes *et al.* 1960).

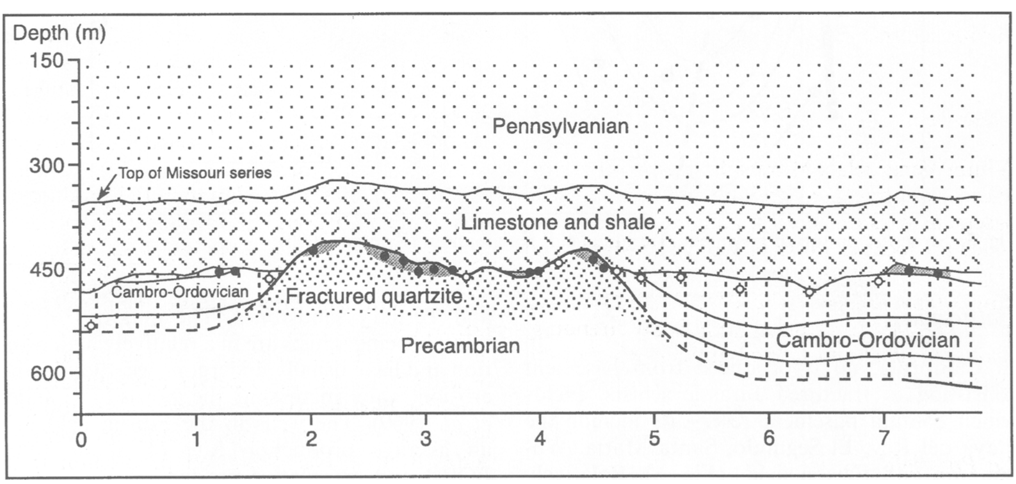

Fig. 7. Kansas basement oil production. Oil is produced from Precambrian basement (in section), most commonly fractured quartzites. Oil is sourced from flanking Cambro-Ordovician or overlying Pennsylvanian rocks. (Landes *et al*, 1960).

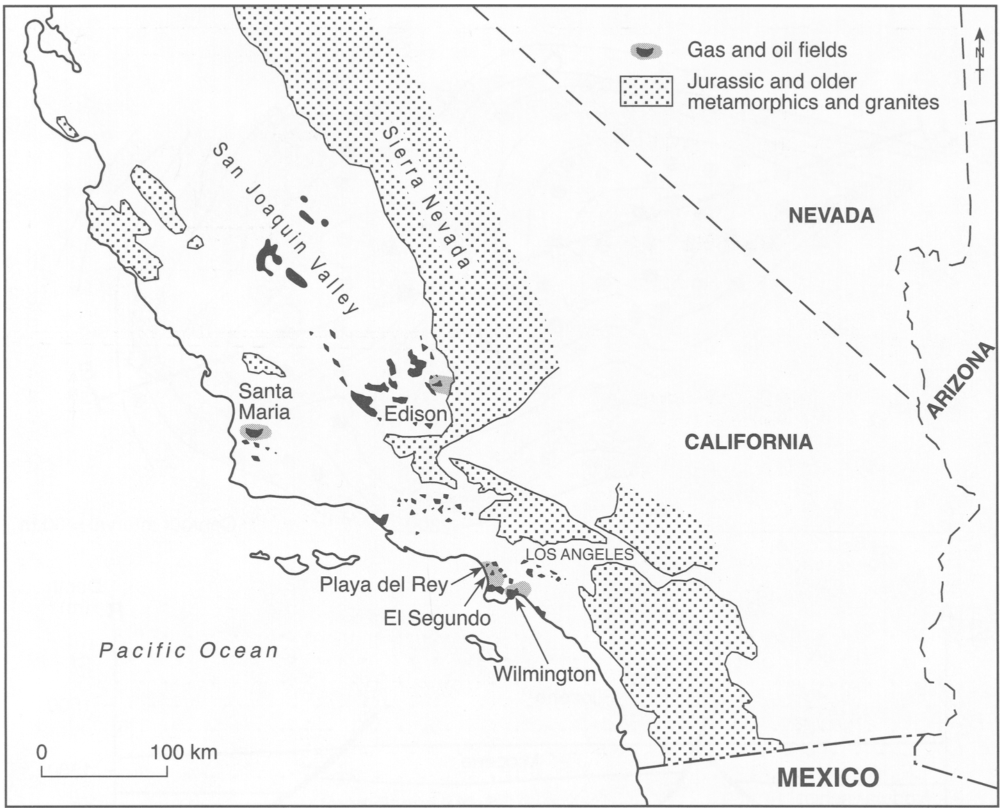

Fig. 8. Map showing the main Californian gas and oil wells of El Segundo, Santa Maria, Wilmington, Playa del Ray and Edison. (Landes *et al.* 1960).

of production varying from 1,200 to 2,000 BOPD. Figure 9 shows a cross-section through the El Segundo field, highlighting the hydrocarbon accumulations in the upper layer of porous schists.

Venezuela

Within Venezuela's Maracaibo basin, oil is produced from fractured granitic and metamorphic basement rocks in the La Paz and Mara fields, which are located 50 km NW of Lake Maracaibo (Fig. 10). The depth to basement in the two fields ranges from 2750 m to 3500 m. These two fields occur along the crest of a NE–SW trending, strongly folded and faulted anticline (Stevenson 1951).

La Paz field

The La Paz field was discovered in 1923 and has produced more than 830 million barrels of oil from low porosity Cretaceous limestones and underlying granitic basement (Nelson *et al.* 2000). The first basement reservoir wells were not drilled until 1953. Cumulative oil production from basement is approximately 245 million barrels and estimated remaining reserves of 80 million barrels occur within basement (Talukdar & Marcano 1994). During the initial development of the field, wells were drilled into basement with an average penetration of 500 m (Chung-Hsiang P'an 1982). Maximum initial production was 11,500 BOPD and the average initial production was 3,600 BOPD. A geological cross-section through the La Paz field is shown in Figure 11.

The Mara field, discovered in 1944, lies on the northeastern extension of the La Paz anticline and has produced 27 million barrels of oil from basement. Remaining reserves are estimated at 5 million barrels. Average penetration into basement was 360 m and initial production averaged 2,200 BOPD. The combined production from basement rocks in these fields exceeded 75,000 BOPD. Cores of basement rocks show intense fracturing, most commonly in vertical planes,

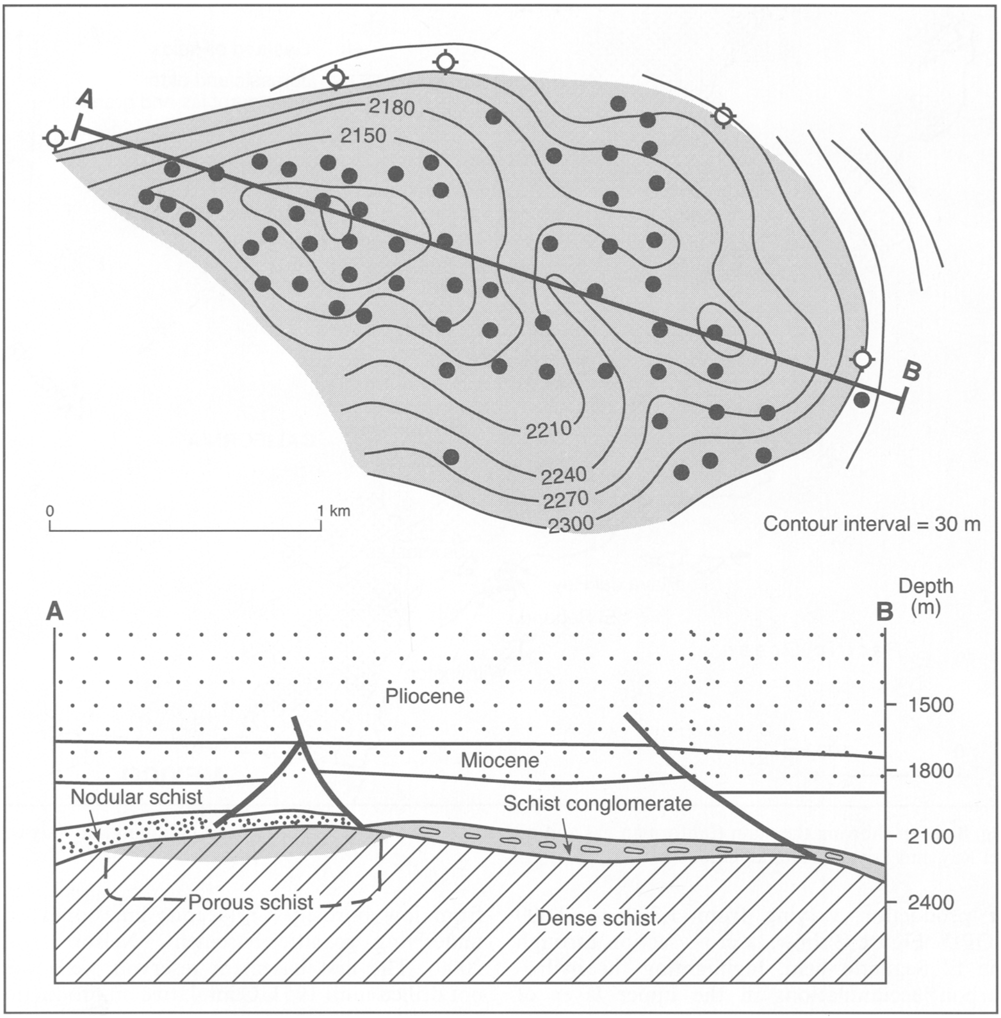

Fig. 9. Cross-section through the El Segundo field, California. The reservoir is in fractured Jurassic schists in the west and schist and conglomerate in the east. The average depth of oil basement production is *c.* 2300 m. (Landes *et al.* 1960).

and many core recoveries are poor (Smith 1955). The oil source rocks are overlying Upper Cretaceous La Luna marine shales which are immature at the fields, but mature to the south of the fields.

Discussion

Characteristics of oil and gas recovery in basement rocks

The following is a generalized summary of the oil field experiences of companies dealing with basement oil and gas fields:

(1) Oil and gas fields in basement rocks are usually discovered 'by accident'. Typically during drilling operations, the well will reach total depth (TD) in basement, encounters oil or gas shows in basement and the well is tested resulting in a basement oil or gas discovery. For example, the Beruk Northeast-1 well, central Sumatra, was targeted for oil in Tertiary sediments. Oil shows were noticed in fractured basement quartzites which resulted in a drill stem test on the top of the basement. This led to the Beruk Northeast oil discovery.

(2) Basement reservoirs can be very prolific if basement is highly faulted and fractured, as in the case of a quartzite reservoir. For

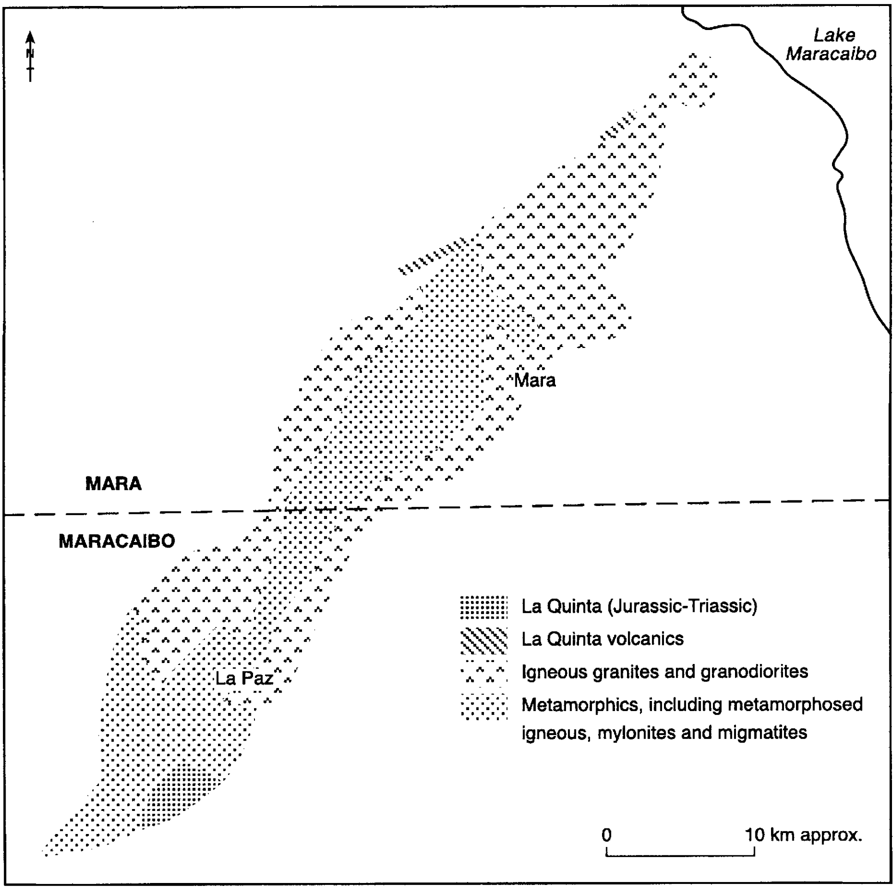

Fig. 10. Summary map showing the main lithologies comprising the Mara and Maracaibo oil fields, Venezuela. (Landes *et al.* 1960).

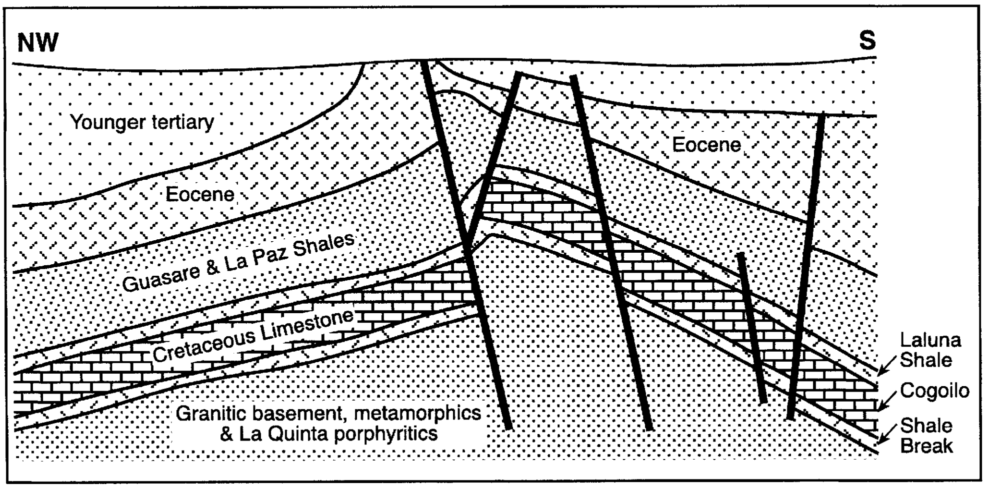

Fig. 11. Vertical section through the La Paz field, Venezuela. (Landes *et al.* 1960).

example, the Bach Ho (White Tiger) field in Vietnam produced in the range of 130,000 BOPD from fractured granite basement (*Offshore Magazine*, August 1994). Also weathered granite can be a highly effective reservoir. Weathering of granites, especially under humid tropical conditions, can result in very porous secondary porosity penetrating 100–200 m into the granite. These weathered granites can appear like coarse sandstones (granite wash sandstones) in hand specimen or core.

(3) Due to basement being often highly fractured and highly permeable, initial oil or gas flow rates are often very high and indeed deceptively high. This may lead to the operator overbuilding the production facilities. When the field is placed on production, rapid production declines may be experienced since the reservoir may have only fracture porosity and minimal matrix porosity. Also, early high volume water influx may be experienced.

(4) Basement oil fields are typically very complex reservoirs with multiple lithologies, possibly two or more fracture systems and multiple oil–water or gas–water contacts. Accordingly, these reservoirs need to be closely studied. Extensive core coverage is critically important, as are full log suites. Coring is typically difficult due to the fractured nature of the reservoir (Lamb 1997). Effective development of basement reservoirs can be a major challenge for reservoir engineers and geoscientists.

(5) Exploration for basement reservoirs should provide provision in the drilling programme to allow for adequate penetration of basement of at least 100 m into the top of basement. The top of basement may be tight but porosity may occur below the overlying tight zone.

(6) Prolific oil and gas fields in basement rocks in Libya, Vietnam, Indonesia, USA, Venezuela and elsewhere serve as a reminder to evaluate, if possible, the underlying basement, especially if the top of basement is structurally high and indications from seismic or regional geology are that the basement may be weathered or faulted.

Summary

The above-mentioned oil and gas accumulations in basement rocks are examples of such fields in three important oil-producing countries. These fields serve as a reminder of the Landes *et al.* (1960) classic paper on petroleum resources in basement rocks, in which the authors succinctly state the following: 'commercial oil deposits in basement rocks are not geological "accidents" but are oil accumulations which obey all the rules of oil sourcing, migration and entrapment; therefore in areas of not too deep basement, oil deposits within basement rocks should be explored with the same professional skill and zeal as accumulations in the overlying sediments.'

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