WORLDWIDE DISTRIBUTION OF PRECAMBRIAN HYDROCARBON DEPOSITS

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ABSTRACT

Bias against the economic discovery of hydrocarbon from Precambrian rock is of long standing. Historically, the professed deterrents to the discovery of oil and gas production from rock older than 580 Ma have ranged from lack of life, and thus absence of source beds, to excessive maturation of existing organic material, to lack of sedimentary reservoir beds. Repeated studies have shown that hydrocarbon is distributed world-wide, principally in Mesozoic and Cenozoic sedimentary rock sequences.

Prior to the 1960s a minor amount of "Precambrian" production was known. These fields normally were created by hydrocarbons derived from Phanerozoic sources migrating into fractured Precambrian igneous rock because of favorable structural associations. Since the 1960s, however, at least a dozen oil and gas fields, several of considerable size, have been discovered in Precambrian reservoir rock, the oil of which was supplied from Precambrian source strata. Such relationships have been made or reported in the East Siberian Platform and the Ural-Volga regions of the U.S.S.R., the Amadeus Basin of Australia, the Sichean and Bohai Bay Basins of China, and the Montana and Lake Superior areas of the United States.

RECENT PRECAMBRIAN HYDROCARBON DISCOVERIES

The geologic literature prior to the 1960s contains reports of commercial and non-commercial hydrocarbon reservoirs associated with Precambrian rock. In these reports the usual explanation involves fractured igneous or metamorphic sequences that have absorbed migrating hydrocarbons derived laterally or vertically from younger source beds. Instances of Precambrian hydrocarbon discoveries reported since the 1960s from the Soviet Union, China, Australia, and the United States are significant because in each the hydrocarbon production is not only reservoir associated, but also initially reported to be source associated with Precambrian rock.

East Siberian Platform

The East Siberian Platform (Irkutsk Amphitheater) Petroleum Province, U.S.S.R., contains the largest proved reservoir of indigenous Proterozoic gas, oil, and condensate. The fact that the marine, shallow-water platform sedimentary rock found here has been subjected to an almost total absence of tectonic activity and is rich in organic matter adds greatly to the potential as hydrocarbon reservoirs of major significance. The potential for this area is so great that Meyerhoff (1980) suggests that "several hundred, perhaps, several thousand, oil and gas fields remain to be found."

At least ten commercial oil or gas fields or both have been reported from the East Siberian Platform; all possess at least one reservoir horizon within the Precambrian section.

In 1962 oil and gas were discovered within arenaceous strata of the Markovo horizon, the upper unit of the Ushakovka suite of Riphean age 450 km northeast of Irkutsk, Siberia (fig. 1). The Markovo horizon is 680 Ma (Meyerhoff, 1980), and possesses good reservoir qualities with porosity up to 13 percent and permeability up to 214 md (Trofimuk and others, 1969). The discovery well tested 549 barrels of condensate and 8,655 Mcf of gas per day on a 25 mm choke. Continued drilling in the area of discovery led to the develop-

ment of the Markovo field with recent proved reserves in excess of 622 Bcf of gas and 16 million barrels of condensate, contained in stratigraphic traps (Meyerhoff, 1980).

Hydrocarbon has been found associated with two additional Precambrian zones in the Markovo sector. The lithology, age, and commercial rating of all three zones are, from oldest to youngest (Meyerhoff, 1980): Bezymyannyy horizon, Ushakovka suite, Riphean age (680 to 925 Ma), 5 to 25 m of angular, poorly sorted, terrigenous sandstone and conglomerate, non-commercial gas reservoir, 4 to 6 percent porosity and less than 1 md permeability; Markovo (Osinskiy) horizon, Usakovka suite, Riphean age (680 to 925 Ma), up to 30 m of quartzose to feldspathic, medium-grained sandstone, oil and gas within possibly the oldest commercial hydrocarbon reservoir in the world, 2 to 13 percent porosity and up to 20 md permeability; and Parfenovo horizon, Motka suite, Venian age (570 to 680 Ma), 15 to 90 m of moderately well sorted, partially feldspathic, quartz sandstone, commercial oil and gas reservoir considered the most important and widespread Precambrian reservoir rock of the East Siberian Platform, 8 to 23 percent porosity and up to 4,300 md permeability.

At least one additional Precambrian hydrocarbon zone was discovered outside of the Markovo section in 1971: Yaraktin horizon, believed to be of ap-

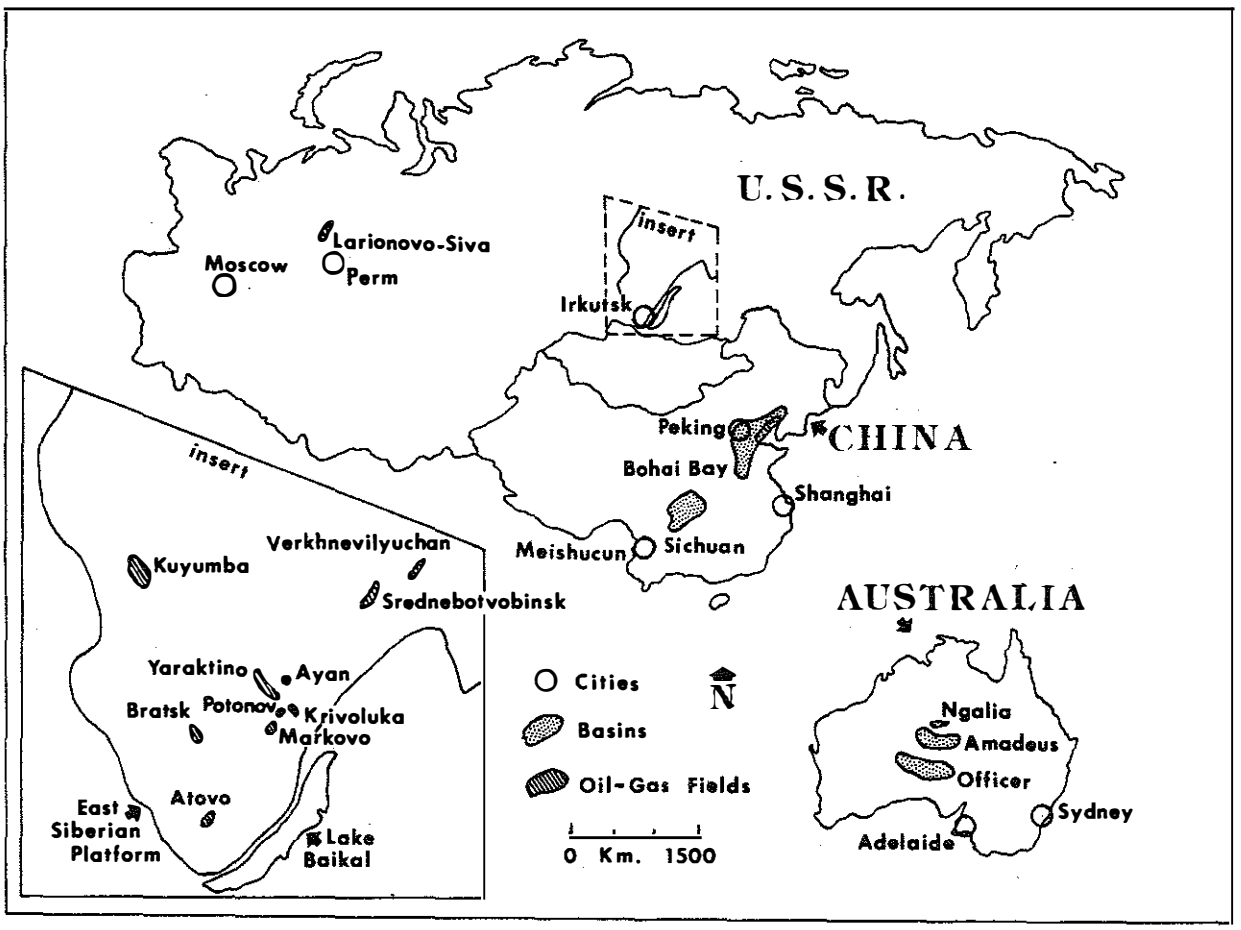

Figure 1. Location of existing and potential Precambrian oil and gas production in Australia, China, and the Soviet Union.

proximate Parfenovo horizon age, 26 m of bar type sandstone, 9 to 10 percent porosity and unknown permeability.

Northern Ural-Volga Region

The upper Precambrian in the northern Ural-Volga region in the vicinity of Perm, U.S.S.R. (fig. 1) is composed of terrigenous-carbonate sedimentary rock of Riphean age and terrigenous rock of Vendian age. The four recognized formations of the Riphean sequence are composed of sandstone and conglomerate redbeds, which grade upward into dark gray siltstone, marl, and carbonate, which, in turn, are overlain by gray sandstone. The Vendian sequence is made up of two formations described as gray, medium-grained clastic rock and shale overlain by green and red clastic rock and shale. The reservoir rock belongs to the Kairovo Formation of Lower Vendian age, and the Kaltasa Formation of Riphean age (Balashova and others, 1983). The general lithology of these units is, respectively, fine- to medium-grained sandstone having a porosity range of 7 to 13 percent, and overlapped carbonate and terrigenous-carbonate strata. Both formations were deposited under reducing environmental conditions, but the older Kaltasa Formation played "the principal role" in the generation of the hydrocarbon (Balashova and others, 1983).

Geochemical indicators demonstrate that the oil differs from and is genetically independent of Paleozoic oil found in the same general region. Murray and others (1980) support a Precambrian age by suggesting that the different chemical composition of the younger oil is one test of an oil being indigenous to the Proterozoic.

Although hydrocarbon reserve data for these strata are not known, apparently commercial prospects have been discovered in the Larionovo and Siva oil fields west-northwest of Perm. Shows of gas are also known in this region.

Amadeus Basin

The Amadeus Basin of central Australia encompasses an area of approximately 180,000 square km within the southwestern part of the Northern Territory, Australia (fig. 1). This basin is composed of unmetamorphosed Proterozoic sedimentary rock conformably overlain by a Paleozoic section of Cambrian and Ordovician strata. The north and south limits of this basin are marked by outcrop of unprospected Archean and Proterozoic igneous basement rock (Webb, 1965). In 1963 the Ooraminna #1, a 1,861 m test, was drilled in this basin. Murray (1965) expressed his belief that this was "the first well ever deliberately programmed to search for oil and gas in Proterozoic sedimentary rocks outside of Russia."

The Ooraminna #1 was spudded in basal Cambrian clastic material of the Arumbera Sandstone and bottomed in Proterozoic halite strata. Overlying this salt the remaining Proterozoic section is composed of carbonate or the Bitter Springs Formation, carbonate and clastic material of the Areyinga Formation, and the Ertatataka Formation, composed of in excess of 600 m of black to green shale containing a thin, 6 m-thick dolomitic limestone. A drill stem test of this limestone flowed 12 Mcf/D methane gas (Murray, 1965). Unfortunately, this was the only significant reservoir facies penetrated, requiring this test to be abandoned (Gardner, 1963). Although a commercial failure, this test was a geologic success as it constituted the "irrefutable evidence of indigenous hydrocarbons in the Precambrian of Australia" (Murray and others, 1980).

In 1963 a limestone reef structure was tested by the Alice #1 well, located 24 km northwest of the Ooraminna #1. The Alice #1 was abandoned, but not

until oil shows were reported from Lower Cambrian carbonate. In late 1963 the first of a series of wells was drilled on the Mereenie structure, which is situated in the central section of the Amadeus Basin. The initial well tested 11 MMcf/D of wet gas from the Stairway and Pacoota Sandstones of Ordovician age. By 1965 commercial gas-condensate production, along with evidence of an oil column, was proved in the lower Paleozoic along the axis of the Mereenie structure (Webb, 1965). Lindner (1985) reported that the "Mereenie field [was] brought on steam in September, 1984, at an initial production rate of approximately 1,500 BOPD."

Testing of the central Australian Proterozoic section has continued in recent years. In 1981 the Davis #1 was drilled in the Ngalia Basin, a small sedimentary trough located immediately north of the Amadeus Basin. It encountered minor gas shows from a "basal Proterozoic shale section" (Durkee, 1982). A year later the Hussar #1 was drilled in the Officer Basin located to the south of the Amadeus Basin and encountered "gas shows in the Proterozoic Browne Beds" (Durkee, 1983). In 1983 the Finke #1, an Amadeus test, reported "hydrocarbon shows in the Proterozoic" (Lindner, 1984).

Although commercial Precambrian hydrocarbon production in central Australia has not been established to date, conditions for such remain encouraging. The thick Proterozoic shale section, continuity of the sedimentation from Precambrian through Ordovician time, and oil and gas production in Lower Paleozoic strata suggest that the Precambrian here may eventually prove commercial.

Sichuan and Bohai Bay Basins

In 1964 the discovery well for the Weiyuan gas field in the central Sichuan Basin, approximately 1,500 km west-southwest of Shanghai, was announced (fig. 1). The principal producing interval of this field lies within the Dengying Formation of Upper Sinian (Late Proterozoic) age. The Dengying Formation is a fractured and vuggy, marine limestone and massive bedded, algal dolomite unit. The low (1%) average matrix porosity and 0.01 to 5 md permeability range is compensated by the regional depositional extent of the tidal flat, platform facies sedimentary rock. Developmental drilling has extended the Weiyuan gas field to 23 km by 9 km.

The gas reservoir rock of the Dengying Formation was deposited under frequent crustal elevation and subsidence, resulting in the creation of numerous sedimentary cycles. Shicong and others (1980) stated that commonly "the lower part of the [typical Dengying] cycle representing the transgressive stage is the source bed; the middle and upper parts of the cycle in the regressive stage are the reservoir bed; and occasionally a sealing bed may be developed at the top of the cycle in the latest regressive state. In the Sichuan Basin as an example, there are at least 20 sedimentary cycles and corresponding source-reservoir-seal combinations in late Sinian ... marine sediments," and the "source and reservoir rocks of the platform facies of the Dengying Formation are very thick."

Without directly addressing the question of source bed, these statements imply that the source rock for the Weiyuan gas field is of the same age as the reservoir rock. In determining the "total quantity of oil generation," Shicong and others (1980) stated that the "Lower Cambrian [yielded] the largest amount, [whereas the] Lower Ordovician ranks second, ..." and "the amount of accumulated oil is in the same order." This comparison suggests that certain of the Late Precambrian rock of China may one day be accepted as a source of hydrocarbons.

The Bohai Bay Basin, also known as the North China Basin, lies to the northeast of the Sichuan Basin. In 1975 the first of more than 40 oil fields producing from the Precambrian in this region was discovered. The initial discovery, the Renqui oil field, is located in the western part of the Bohai Bay Basin, approximately 125 km south of Peking in Hebei Province. The principal reservoir is a stromatolite-rich limestone and siliceous dolomite sequence of the Wumishan Formation of Sinian age. Reservoirs of secondary importance are found in pre-Sinian granite-gneiss and sandstone of the Sinian Changcheng Formation.

Fault-block movements in the Tertiary uplifted this Precambrian section and created fracture porosity. Later weathering and leaching of the carbonate enhanced the porosity to the range of 5 to 10 percent. This leaching was concentrated along pre-existing fractures and created horizontal and vertical karst zones. During the Eocene the potential reservoir rock was overlapped by lacustrine deposits of the Shahejie Formation (Quanheng, 1984). As oil was generated, it migrated along the fault zones into the karst-fracture system of individual buried hills (Qi and Xie-Pei, 1984). The carbonate reservoirs are excellent producers, averaging over 4,000 barrels daily per well, and account for 85 percent of the buried hill oil pools.

Dunshi and Guangming (1980) suggest associations other than Tertiary age petroleum in Proterozoic reservoir rock in the Bohai Bay Basin. They predict discovery of "pools ... associated with Sinian and Paleozoic source and reservoir rocks."

Northern Rockies and Southern Lake Superior Region

In September 1983, the #1 Paul Gibbs well was spudded in Flathead County, northwestern Montana, by the Atlantic Richfield Company and was a search for "subthrust Paleozoic sediments underlying the Precambrian Belt Series" (Teselle and others, 1985). The hole was drilled to 5,418 m and the bit never exited from Precambrian overthrust rock. Although a disappointment to the operator, this test made national news when reports indicated "natural gas shows [were encountered] in the Precambrian rocks from about 2,200 m total depth" (Shirley, 1985). These gas shows "intercepted in rocks 1.43 billion years old represent very possibly the oldest indigenous hydrocarbons that have been drilled in the world" (Shirley, 1985). The reservoir rock for the gas show is metasiltstone and quartzite of the Pritchard Formation of the Belt Series. Porosity and permeability have been created by fracturing. The rock contains 0.2 to 0.3 percent total organic carbon, and analysis of reservoir water "tested fairly fresh -- implying maybe the reservoir has been flushed and the gas may not be indigenous" (verbal communication, E. Frodeson, geologist, Atlantic Richfield, 1985). This suggestion of post-Proterozoic-age gas migrating into fractured Precambrian rock is enhanced by the report that the "highest gas shows" were encountered at a thrust fault penetrated at 5,180 m (Shirley, 1985).

Hydrocarbon has been known for decades to exist in the southern Lake Superior region. Hydrocarbon in the form of crude petroleum and solid material similar in appearance to gilsonite (Daniels, 1982) is contained principally within the basal 10 m of the Nonesuch Formation of Proterozoic age. This source formation has been variously dated from 1,075 Ma ("a close upper limit to the time of deposition") by Chaudhuri and Faure (1967) to 1,047 Ma by Ruiz and others (1984). This latter age is considered by Kelly and Nishioka (1985) to be "a minimum age for the oil."

No surface seeps are known. Published reports describing this oil are based upon samples collected underground in the Copper Range Mine, White Pine, Michigan. The oil is considered indigenous to the Nonesuch because of the presence and type of contained fossil micro-organisms (Meinschein and others, 1964), and correlation of chemical properties of the oil to pulverized source shale (Eglinton and others, 1964; Barhoorn and others, 1965). The oil and its extracts resemble parafinic crude oil of Paleozoic age (Meinschein and others, 1964). The oil has been preserved because temperatures within the Nonesuch Formation have apparently never been high (Barghoorn and others, 1965) nor have they exceeded 100° C (Brown, 1971). The hydrocarbon is the oldest known crude oil (Daniels, 1982; Barghoorn and others, 1965). The oil has been determined as biological in origin (Eglinton and others, 1964) and is the final product of primary photosynthetic processes (Barghoorn and others, 1965). The source bed for the oil is suggested to have been deposited under conditions of a near-shore, deltaic (Barghoorn and others, 1965), estuarine-lagoonal environment subject to marine (Moore and others, 1969) or fresh water (Pettijohn, 1957) influxes.

CONCLUSIONS

The discovery within the past 25 years of accumulation of oil and gas in Precambrian reservoir rock supplied by Precambrian source strata proves that geologic age is not an indicator of the presence or absence of hydrocarbon. Rather, the distribution of hydrocarbon anywhere within the geologic column is controlled by conditions of structure, extent of maturation or organic material, lithology, and the effective presence of source, reservoir and trap rock. Any Precambrian province which possesses an idealized combination of these factors must be considered priority exploration territory.

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