Petroleum Potential in the East Siberian Region*

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1. Introduction

A future pipeline project that will transport crude from oilfields in East Siberian region to Nakhodka located along the coast of the Japan Sea is under discussion and has gradually been concreted its main framework. On the "Pacific Route of Oil Pipeline Plan", a question remains, however, over volumes that could be committed to the line. Although significant amount of oil reserves has been confirmed in Siberian region, most of them are emplaced in West Siberia. A widely accepted view in Russia is that 30 million tons will be the maximum amount of annual oil supply through the new pipeline on the basis of the known proved oil reserves in the East Siberia. The larger the amount of oil supply the better for Japan, since Japanese expect that the dependence on Middle East region in terms of oil supply to Japan could lessen by this new pipeline. One idea that 90 million tons of oil in total [1)] (50 million tons for Nakhodka, 30 million tons for China, and 10 million tons for local use) is supplied annually through the new pipeline, has been proposed (Kanekiyo, 2003) [2)]. *In fact, oil production in the East Siberian region has been constrained by a lack of oil pipelines. If new oil pipelines connect between the East Siberian region and the Pacific Ocean, oil production and further exploration could be accelerated in the East Siberian region. Consequently, the proved oil reserves in East Siberia will be considerably increased* (Kanekiyo, 2003) [2)].

The first thing to be considered is if significant new discoveries are made in the East Siberian region. In order to evaluate the inherent oil potential in the East Siberian region, its "unique geological settings" must be evaluated. It is considered that the importance of these geological issues increases as the pipeline plan is matured. The basic purpose of this report is to discuss the

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* A part of this report (oil resources estimation results and its process) was presented by the Author in "Nakhodka Pipeline Study Team (members are from IEEJ, the Federation of Economic Organization Japan, JNOC and related private companies)" on November 28, 2003.

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1) The total amount of 90 MMt of oil supply for 30 years is equivalent to approx. 20 BBO.

2) Kanekiyo Kensuke (2003), The Significance of Siberia Oil Pipeline and Essential factors for Its Realization (in Japanese), Dec. 2003, web-site of The Institute of Energy Economics, Japan. In this article, the following conceptual idea is further mentioned; transferring of crude from West Siberia should be started first and is followed by crude from East Siberia in future.

inherent oil potential in the East Siberian region. A new geological concept "Basement-high Crest Play" is proposed and the results of an original estimation on petroleum resources in the East Siberian region are also presented.

2. General Geology of Siberian Region

Siberian region is clearly divided into western and eastern parts in terms of geological settings. The western half of the Siberian region is called West Siberian Lowlands, and is one of the most extensive lowlands of the globe. This lowland is identical to West Siberian Sedimentary Basin (WSSB) geologically. The WSSB is widely extended to the area of 2.5 million square kilometers between Ural Mountains in the west and to Yenisey River in the east (see Fig.1). The WSSB was formed with gigantic depression of basement rocks during Late Permian and Triassic (about 250 Ma, million years ago) and infilling by a thick assemblage ranges from 3,000 meters up to 8,000 meters of Permian, Triassic, Jurassic, Cretaceous, Tertiary and Quaternary deposits.

Source: The Institute of Energy Economics, Japan (IEEJ)

Fig.1 Location Map of West Siberian Sedimentary Basin and Siberian Platform

In 2000, U.S. Geological Survey conducted World Petroleum Assessment, and examined worldwide 937 identified geologic provinces in terms of total known petroleum volumes. As the assessment results, the WSSB contributes 14.3 percent of the world total known petroleum volume and is ranked as the top (USGS, 2001) [3)]

In the eastern half of the Siberian region, Siberian platform is widely extended between Yenisey River to the west and Lena River to the east (see Fig.1). The Siberian platform has been formed by uplifted basement rocks [4)] composed of Archean (2,500 Ma and older) metamorphic rocks and igneous rocks. *At the beginning of Riphean time (most of the Late Proterozoic, 1,650-650 Ma), the basement of the craton was rifted and the rifts were filled with thick clastic and carbonate rocks* (USGS, 2001) [5)]. *The basement is overlain by Riphean (most of Late Proterozoic age, 1650-650 Ma), and early Paleozoic rocks. Younger rocks are relatively thin* (USGS, 2001) [6)]. *Vendian-lower Paleozoic rocks composed a platform sedimentary cover of the entire Siberian craton. Vendian (650-570 Ma) rocks are quartzose sandstones, quartzite, and shales in the lower part and dolomites, in places with anhydrite interbeds in the upper part* (USGS, 2001) [5)].

The Siberian platform is in fault contact surrounding with a series of depressions in the depth. These depressions are filled with thick upper Paleozoic-Cenozoic clastic rocks and effusive and intrusive volcanics, and form a series of elongated sedimentary basins (see Fig. 1). These depression-type sedimentary basins are Yenisey-Khatanga Basin and Lena-Anabar Basin in the northern edge of the platform, Verkhoyansk Basin in the northeastern edge of it, and Lena-Vilyuy Basin in the eastern edge of the platform. The total of the Siberian platform with surrounding basins extends to the area of 3.7 million square kilometers (about ten-times of the area of Japan).

3. Existing Oil Fields in the East Siberian Region

According to the widely accepted theory on petroleum geology, the existence of "Petroleum System" is indispensable to form hydrocarbon fields in each geological province. The Petroleum system is the essential elements (source, reservoir, seal, and overburden rocks) and processes (generation, migration, accumulation and trap formation). Sedimentary basins have been regarded

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3) USGS (2001), U.S. Geological Survey World Petroleum Assessment 2000, USGS Web-site

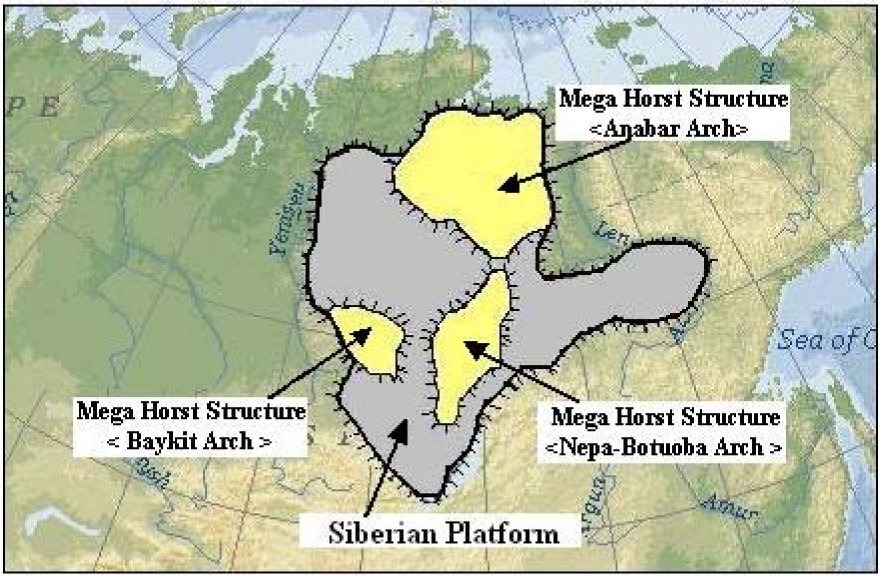
4) Oldest and crystalline rocks are grouped and are called "basement rocks". Basement rocks are part of fragments of earth's crust. The fragment is generally called Craton.

5) USGS (2001), Petroleum Geology and Resources of the Nepa-Botuoba High, Angara-Lena Terrace, and Cis-Patom Fore deep, Southeastern Siberian Craton, USGS Web-site

6) USGS(2001), Petroleum Geology and Resources of the Baykit High Province, East Siberia, Russia, USGS Web-site

as preferable targets for hydrocarbon exploration, as the basins have favorable geological settings to form the petroleum systems. Whereas, the Siberian platform consisted of Archean basement and the overlaid sediments consisted of the oldest rocks (the Proterozoic and the Lowest Paleozoic) in the world, has been treated as poor reservoir rocks with less prolific for hydrocarbon generation. Any petroleum system can be hardly established in the Siberian platform. Thus, the East Siberian region has been generally categorized into less prospective area for oil exploration.

With all such geological conditions, an oil discovery was made at Osa 130 kilometers west of Irkutsk by a well of 1,560 meters in depth in 1954. Although no-commercial size, it was the first oil production in the province. At the same time, geological survey was conducted and mega-sized Nepa-Botuoba Arch structure (axis length of 1,000 kilometers) was identified in southeast of Siberian Platform. The first oil well at Osa was confirmed to situate at southwestern part of the arch. At discovery of Osa, oil was produced from Lower Cambrian (550 Ma, the Lowest of Paleozoic) dolomites. These events were the turning point to activate oil explorations and have led to the discoveries of large oil-gas fields in the East Siberian region (Motomura, 1980) [7].



Source: The Institute of Energy Economics, Japan (IEEJ) drafted from data of various sources.

Fig. 2 Distribution Map of Mega-sized Horst Structures on the Siberian Platform

3.1 Distribution of the Existing Oil-gas Fields

The crystalline basement forming the Siberian platform is blocked by faults. Each basement

[7] Motomura. Masumi (1980), Geology and hydrocarbon Potential of Siberian Platform (Vol.1); "Lena-Tunguska Region" (in Japanese), Journal of Oil Development, Japan National Oil Cooperation, Oct. 1980

blocks is vertically displaced hundreds to thousands of meters due to faulting. Depressed basement blocks (graben-type) were overlain by thick accumulations of Paleozoic age and likely to include rich organic materials. Whereas uplifted basement blocks (horst-type) have formed arch structures (the term "Anticlise" is used in Russia) and have been covered by relatively thin depositional rocks. It is envisaged that only small amount of organic material has been deposited over the arch structures due to lean of sedimentary accommodations. Accordingly, horst-type basement blocks are regarded as lean oil-yield potential area as compared with graben-type. **However, the truth is that no significant oil fields have been discovered in graben-type on the Siberian platform. On the contrary to the presumption, large oilfield discoveries have been made only on the horst-type arch structures.**

Three mega-sized horst structures are known in the Siberian platform. They are "Anabar-Arch", "Nepa-Botuoba-Arch", and "Baykit-Arch" (see Fig.2). The terms "Anticlise", "High" are used in Russia and by USGS, respectively. In this report, the terms "Arch" is used for mega-sized horst-type structure and is separated from the terms "High" which is used for smaller dome-shaped feature on the Arch structure. **Most of the existing oil-gas fields are concentrated on the both of the Nepa-Botuoba Arch and the Baykit Arch in the East Siberian region**. Although, the rest "Anabar-Arch" forms the most up-lifted area in the Siberian platform, *the crystalline basement crops out on top of the Arch, and relatively thin lower Paleozoic rocks cover its slopes* (USGS, 2001) [5)]. Under such geological conditions, Anabar-Arch has been regarded as non-prospective area for oil exploration.

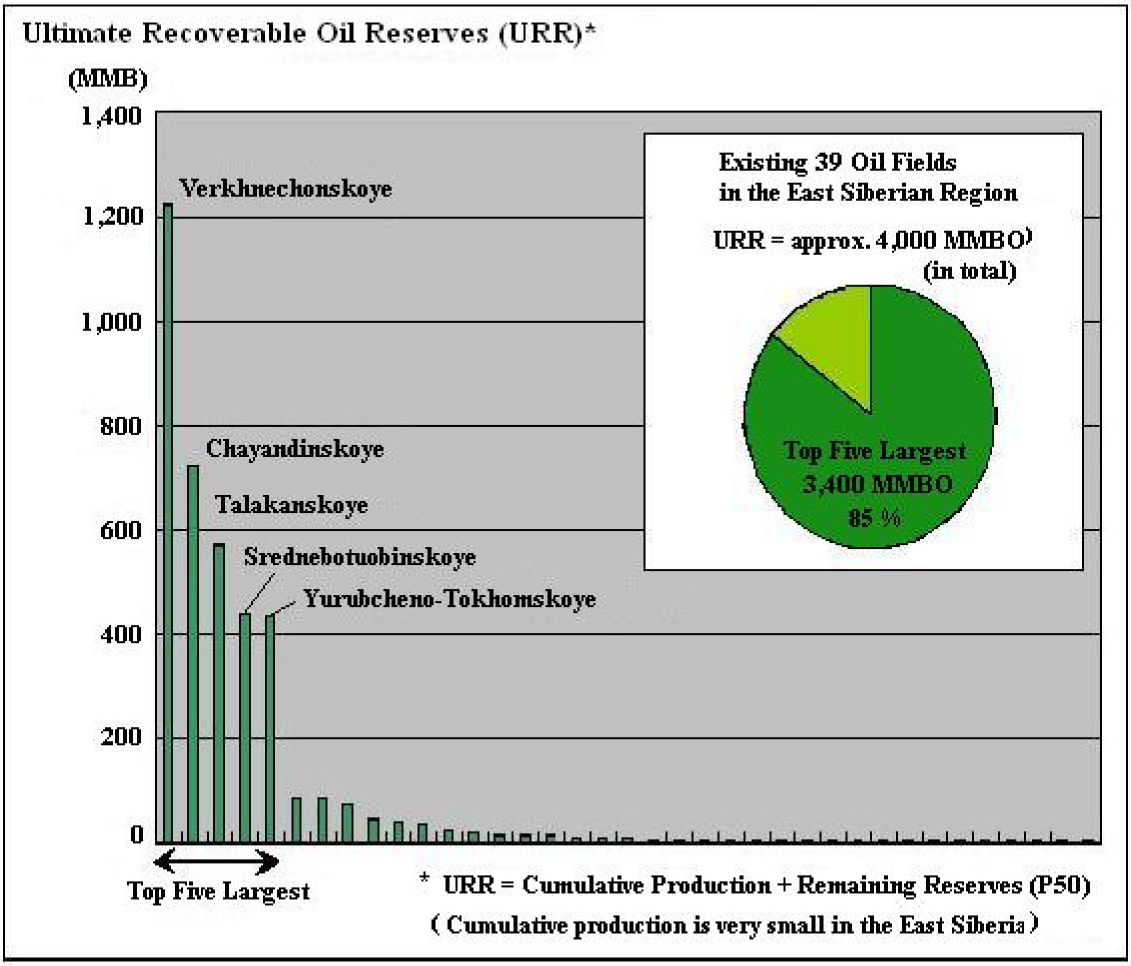
3.2 Oil Reserves Concentrated Areas

Ninety-nine (99) oil and gas fields have been discovered in East Siberian region, of which 39 are oil and oil-gas fields and the remaining 60 are gas-condensate fields. The ultimate recoverable oil reserves [8)] of the 39 oilfields are about 4,000 MMBO (million barrel of oil) in total (IHS Energy, 2002). The top five oil-gas fields (Table 1) contain huge amount of proved reserves of 3,400 MMBO in total, and contribute a disproportionately large 85 percent of the total proved oil reserves in the East Siberian region (see Fig. 3).

The first, second, third and fourth largest oilfields are situated on the Nepa-Botuoba Arch, and the fifth largest is situated on the Baykit Arch. Moreover, those five largest oilfields are all

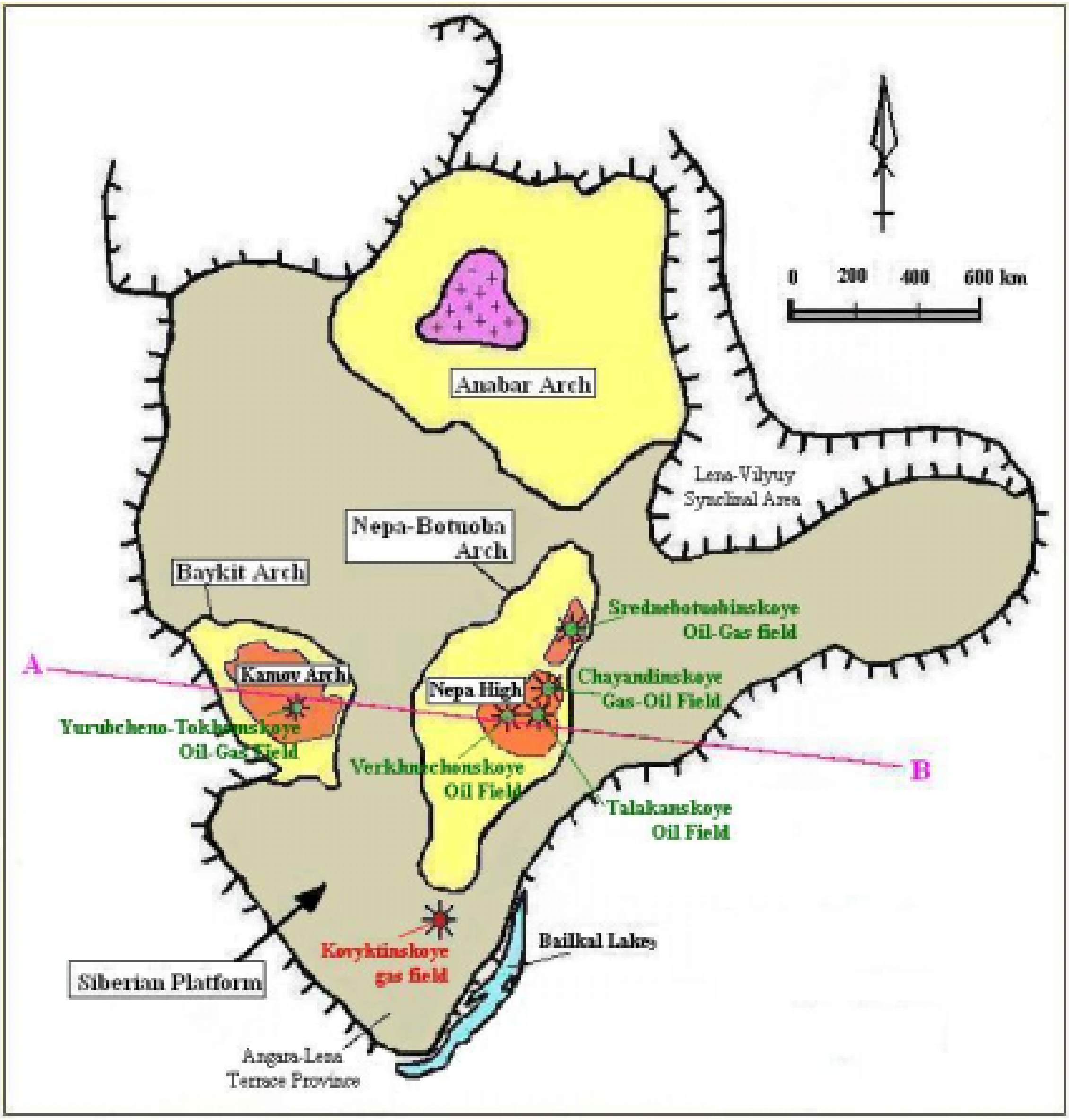
8) Ultimate recoverable oil reserves (URR) are the total of cumulative oil production and recoverable oil reserves. The figure of the URR in the East Siberian region is nearly equal to P50 reserves (proved plus part-probable recoverable oil reserves), since cumulative oil production in the region is very small.

situated at the basement-uplifted high structures on the crest part of the Arch structures (see Fig. 4). These uplifted high structures are named “Kamov Arch” on the Baykit Arch and “Nepa High” on the Nepa-Botuoba Arch. **Thus, most of the known recoverable oil reserves in East Siberian region concentrate on the small crest parts of the two mega-sized Arch structures (see Fig. 4).**



Source: The Institute of Energy Economics, Japan (IEEJ) drafted it based on data of IHS Energy etc.

Fig. 3 A Histogram of Existing Large Sized Oil Fields in the East Siberian Region (Oilfields: greater than 10 MMBO of URR)



Source: The Institute of Energy Economics, Japan (IEEJ) drafted from data of various sources.

Fig. 4 Distribution Map of Two Mega-sized Horst Structures and Giant Oilfields
The Siberian Platform

Table 1. Top Five Oil Fields in the East Siberian Region

Rank	Oil Field Name	The Western's Estimations* URR (produced + P50 reserves)	Russia's Estimations** (A+B+C1 category)
1st	Verkhnechonskoye	1,220MMBO, 1.1TCF	1,148MMBO, 0.4TCF
2nd	Chayandinskoye	730MMBO, 5.6TCF	306MMBO, 13.4TCF
3rd	Talakanskoye	570MMBO, 1.0TCF	760MMBO, 1.2TCF
4th	Sredonebotuobinskoye	440MMBO, 5.5TCF	390MMBO, 5.3TCF
5th	Yurubcheno-Tokhomskoye	430MMBO, 3.2TCF	420MMBO, 3.3TCF
	Total of Top Ranked Oil Fields, Oil-Gas fields	**3,390MMBO, 16.4TCF**	**3,024MMBO, 23.6TCF**

* IHS Energy, 2002: P50 is equivalent to technically recoverable resources in terms of USGS, or equivalent to proved + part-probable reserves (quoted from IHSE-Field & Reservoir Reserves April 2003).

** Ministry of Natural Resources of RF, Moscow, 2001 (in Russian), quoted from "Energy Systems Institute (2002), Study on Natural Gas Trade in Northeast Asia Sub-region, 143 pages"

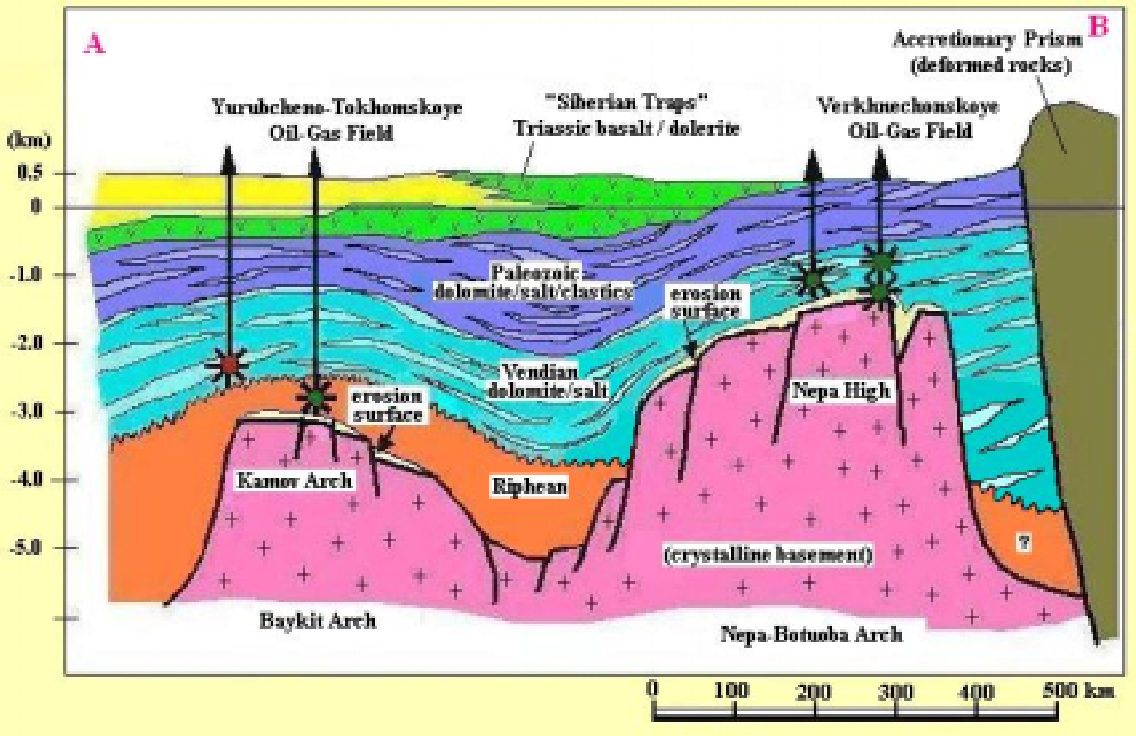
4. Arch Structures and Oil-bearing Formations

4.1 Baykit Arch

The Baykit Arch is the third largest regional high on the Siberian platoform, and is about 500 kilometers by 500 kilometers wide (see Fig. 4). The Arch has been formed by uplifting of the basement complex that consists of Archean (older than 2,500 Ma) and Lower Proterozoic crystalline granite and gneiss. The top surface of the basement was once exposed to weathering and eroded. Then, a thin sand layer was formed as a crust of the basement top. The basement with the thin sand layer on the top was overlain by Riphean (Late Proterozoic age 1,650-650 Ma). The Riphean is composed mainly of limestone, dolomite and clastic rocks. Vendian (latest Proterozoic, 650-570 Ma), and early Paleozoic rocks cover on the Riphean.

Several uplifted basement-highs are situated on the Baykit Arch. The largest high structure named "Kamov Arch" which is 350 kilometers by 250 kilometers in size is situated at the top and central part of the Baykit Arch. The largest oil-gas field named Yurubuchen-Tokhomo (ranked as the fifth largest in the East Siberian region, see Table 1) is situated over the crest part of the Kamov

Arch. *The relief of the erosion surface of the Riphean deposits controls the structure of the Yububchen-Tokhomo oil-gas field.* (Beilin et al., 2002) [9].



Note: Approximate location of cross section A-B in Fig. 4.

Source: The Institute of Energy Economics, Japan (IEEJ) modified from USGS, 2001 and added data of IHS Energy etc.

Fig. 5 Geological Cross section through the Two Mega-sized Horst Structures, the Baykit Arch and the Nepa-Botuoba Arch

<Yurubuchen-Tokhomo Oil-gas Field>

Fig. 5 presents geological cross section running through both of the Baykit Arch and the Nepa-Botuoba Arch (cross section line is shown A-B in Fig. 4). *The major oil and gas reservoirs of the Yurubuchen-Tokhomo oil and gas field occur in the Riphean carbonate complexes dated at 1,400-1,000 Ma. The type of the Ripean reservoir is carbonate, carvernous-fractured, with the open porosity of the matrix from 0.35 to 2.4 percent, and with fractures-cavernous porosity to 6.5 percent. The rates of production are low and medium as the pools are structurally complex.*

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9) Beilin Yu.A., et al. (2002) : Geology and Developmental Perspectives of Oil, Gas and Helium Resources of the Lena-Tunguska Petroleum Province, Energy Cooperation in Northeast Asia, The 3rd International Conference ECNEA-2002, Sept., 2002

Along with hydrocarbon pools in the Riphean deposits, some pools are in the sandstones of the lowest Vendian (Vanavara Formation) and the middle Vendian (Oskoba Formation). The effective thickness of the reservoir of the Vanavara varies from 0 to 7.6 meters. These sands pinch out and form the traps (Beilin et al., 2002) [9)].

The URR (cumulative production plus P50 reserves) of the Yurubuchen-Tokhomo oil and gas field is estimated 430 MMBO and 3.2 TCF (trillion cubic feet of gas) (IHS Energy, 2002). The hydrocarbon pools of the field are basically divided into numerous blocks by faults. Most of blocks are remaining unexplored and they occupy vast area of the Baikit Arch. Many Russian geologists believe that the zone contains giant oil and gas resources and the potential for reserve growth is high. In Russia's estimation (Ministry of Natural Resources of RF, Moscow, 2001), A+B+C1 (equivalent to IHSE's P50 reserves, or proved plus part-probable reserves in the Western definition) of the field reaches 428 MMBO, which is close to the estimation of IHS Energy. Whereas A+B+C1+C2 category (equivalent to proved plus probable plus part-possible reserves in the Western definition) is estimated 2,670 MMBO with 14.6 TCF by Russian for the field.

<Other Oilfields on the Baykit Arch>

Furthermore, two other fields are on the Kamov Arch. These are Kuyumbinskoye gas-oil field and Telsko-Kamov oil field. Russian estimate huge C2-reserves (equivalent to probable plus part possible reserves in the Western definition) in these additional fields (Table 2). In case that these C2 reserves of these three oil-gas fields upgrade to C1 category, the Baykit Arch could be the biggest oil emplacing zone which would contain greater than 7,000 MMBO of P50 reserves (see Table 2).

Table 2. Reserves of Oil-gas fields situated on the Kamov Arch, the Baykit Arch

Oil-Gas Fields	The Western Estimation* URR (P50 reserves)	Russian Estimation** (A+B+C1+C2)
Yurubchen-Tokhom	430 MMBO, 3.2 TCF	2,670 MMBO, 14.6 TCF
Tersko-Kamov	10 MMBO	2,830 MMBO
Kuyumbin	10 MMBO	1,530 MMBO, 10 TCF
Total in the Kamov Arch	**450 MMBO, 3.2 TCF**	**7,030 MMBO, 24.6 TCF**

* IHS Energy (2002)

** Ministry of Natural Resources of RF, Moscow, 2001 (in Russian), quoted from "Energy Systems Institute

(2002), Study on Natural Gas Trade in Northeast Asia Sub-region, 143 pages”

<Oil Characteristics and Source Rocks>

The oil of Yurubchen-Tokhom field is light (42˚-45˚API) and has a low sulfur contents (0.2-0.3 percent). Its group composition is dominated by paraffinic and naphthenic hydrocarbons. The oil is devoid of asphaltenes, but has a significant content of resins (21-27 percent). The geology of the province is not well understood, and many questions remain regarding major elements of the petroleum system: In particular, uncertainties in determination of source rocks and timing of hydrocarbon generation and migration. Based on the apparent absence of potential oil source rocks in the Vendian-Lower Cambrian sequence, it may be concluded that the source rocks occur in the Riphean interval (USGS, 2001) [6)].

4.2 Nepa-Botuoba Arch

The Nepa-Botuoba Arch is the second largest dome-shaped regional high, which extends southwest to northeast for more than 1,000 kilometers and with width of 500 kilometers.

The sedimentary rock cover of the region overlies the Archean-Lower Proterozoic basement of Siberian craton. The basement is covered by Vendian (Uppermost Proterozoic, 650-570 Ma) clastics and carbonate rocks. Most of the overlying sedimentary section consist of Cambrian and Ordovician salt-bearing formations. Older Riphean sedimentary rocks are largely absent. The regional high consists of some uplifts that are separated by shallow structural saddles. The largest uplift is the “Nepa High” in the southern part of the Nepa-Botuoba Arch. A number of basement-related smaller structures control the location of hydrocarbon fields (USGS, 2001) [5)].

Twenty-two (22) out of the 39 existing oil fields and oil-gas fields in the East Siberian region are situated on the Nepa-Botuoba Arch. The total of the URR (equivalent to proved plus part-probable reserves) of the 22 oil or oil-gas fields occupy almost 87 percent of that (about 4,000 MMBO) of all 39 fields in East Siberian region (from the data of IHS Energy, 2002).

<Verkhnechonskoye Oil-gas Field>

The largest field Verkhnechonskoye is situated on the west flank of the Nepa High. The field is divided into blocks by faults of different trends. The thickness of some Vendian horizons varies from 2 to 18 meters. The oil-bearing formation is 4-5 meters, and the 8-10 meters thick member composed of mudstone served as a seal. A reservoir bed named B13 is widespread throughout the field up to its pinching out in the northwest. The bed mainly consists of sandstone, mudstone and *siltstone. Its thickness varies from 0 to 18 meters and controlled by a regional basement rising. A thickness of effective oil-saturated formation varies from 0.7 to 5.5 meters. Open porosities range 10-20 percent with permeabilities from 300-400 mD (mili-darcy). Hydrocarbon pools in the bed are non-anticlinal, bedded, in blocks, lithologically limited and stratigraphically sealed* (Beilin et al., 2002) [9)].

Beilin et al. [9)] also states that ***hydrocarbons inflows were produced from crust of weathering of the basement according to observations in several wells. A fault in the northeast of the field has a significant vertical throw of displacement across the surface of the crystalline basement reaching 100 m.*** It further states that ***these faults undoubtedly controlled the processes of oil and gas accumulation, which is evidenced by a significant difference in formation pressures (2 MPa, mega-pascal) in the adjacent blocks.***

<Chayandinskoye Gas-oil Field>

The Chayandinskoye field is the second largest oil field and is confined to the eastern slope of the Nepa High. The main reservoir is a sandstone bed, non-anticlinal, lithologically limited. Productive thickness varies from 2 to 26 meters (Due to its extreme old in age of the formations, the sand layers has been significantly compacted, separated and faulted. The present feature of the formation must be considerably different from its depositional conditions.) *Porosity ranges from 9 to 16 percent. In the southeast of the field, faults subdivide the pool into several blocks that have independent gas-liquid contacts* (Beilin et al., 2002) [9)].

<Talakanskoye Oil Field>

The Talakanskoye field is the third largest oilfield and is situated in southern part of the Nepa High. *Hydrocarbon pools have been revealed in Vendian sandstones and Osa dolomites. A pool of Vendian sandstones is bedded, non-anticlinal, lithologically limited. A thickness of the horizon is up to 5 meters. Faults subdivided the pool horizons into blocks. Open porosities in sands range from 8 to 10 percent, and permeability reaches 10 mD. Reservoir rocks of Osa dolomites are fragmental limestones surrounding organic buildups. A thickness of the horizon is 30-35 meters, porosity ranges from 12 to 19 percent, permeability from 200 to 250 mD. The pool exhibits lithological control* (Beilin et al., 2002) [9)].

<Oil Characteristics and Source Rocks>

Oils discovered in the Nepa-Botuoba Arch are of low gravity (37˚-45˚API) and they have low *sulfur (0.1-0.3 percent) and low paraffin (0.6-1.7 percent) contents. The oils contain small amounts of resins (0.8-5.9 percent), and asphaltenes are almost completely absent. In most fields they contain high percentage of ethane and heavier homologues (12-15 percent) and small amounts of carbon dioxide (less than 1 percent); commonly significant concentrations of nitrogen (5-8 percent) and helium (0.2 percent)* USGS (2001) [5)].

Vendian and Lower Cambrian rocks, which overlie the crystalline basement and include the entire hydrocarbon reserves of the petroleum system, probably do not contain source rocks. TOC (total organic carbons) in analyzed samples in Vendian clastics ranges from 0.1 to 0.3 percent. Carbonate rocks that both underlie the salt and composed beds alternating with salt have very low TOC contents generally not exceeding 0.2 percent. However, the composition of biomarkers in oils indicates high maturity of source rocks (USGS, 2001) [5)]. USGS concluded that *oil and gas fields of the petroleum system of the Nepa-Botuoba region were probably derived from different source rocks* [5)].

4.3 Giant Gas Fields

Seven (7) fields out of 91 gas fields (including gas/oil fields) are giant gas fields (greater than 3.5 TCF of proved reserves). Three gas-oil fields out of the seven giant gas fields are situated on the Nepa-Botuoba Arch. The rest four are situated in Angara Lena Terrace, Vilyuy Basin, Katanga Saddle and Yenisey-Khatanga, respectively.

Kovyktinskoye field, located 350 kilometers northeast of Irkutuk has conspicuously huge gas reserves among the seven giant gas fields. Kovyktinskoye field is situated in Angara Lena Terrace, and is not belonging to any Arch structure (to the south of the Nepa-Botuoba Arch) (see Fig. 4). Rusia Oil presented its current gas reserves (as of June 2003) of 1.407 trillion cubic meters (in C1 category) and 0.572 trillion cubic meters (in C2 category) at an international conference [10)]. The reported gas reserves of the Kovyktinskoye field can be converted into about 70 TCF (in C1+C2 category). Rusia Oil also presented at the conference that the field also contains 83.37 million tons of huge condensate reserves in proportion to gas reserves.

The pool of the gas-condensate field is in the Lower Vendian that is composed of sandstones underlain and overlain by silty mudstone intervals. A thickness of sand horizon reaches 150 meters at maximum. The sandy reservoirs are dipping toward NNW in direction. The up-dip side (SSE in direction) is lacking seismic data due to the mountain range on the surface.

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10) The 8th International Conference on Northeast Asia Gas Pipeline, held in Shanghai on March 8, 2004

Therefore, the entire structure and trap mechanism have not been verified. The total gas reserves of the gasfield may increase much more adding the up-dip portion of the field.

High concentration of helium gas (0.26 percent) is another characteristic of the gas-condensate field. Something special geological concept should be required to understand how such super-giant gas-condensate field has been formed.

5. Oil Migration and Accumulation Mechanism in E. Siberia

The East Siberian oils are emplaced in mainly Riphean dolomite (1,650-650 Ma), the Vendian-Cambrian sandstones and dolomites (650-570 Ma). Dolomite is common oil-bearing reservoir rock type in the world oil provinces. However, the age (Pre-Cambrian and Cambrian) of which is the oldest in the world. Generally, such old layers have not been targeted for petroleum exploration in the world. This is one of the characteristics of petroleum provinces in the East Siberian region.

5.1 Important Features in the East Siberian Region

Most of sub-areas in the East Siberian region can be categorized into unexplored area. However, *more than 1,000 of exploratory and delineation wells have been drilled in the Nepa-Botuoba and adjacent provinces* (USGS, 2001) [5)]. That is enough number of wells to reveal the general tendency of oil fields distribution and geological characteristics of oil-gas fields in the Nepa-Botuoba Arch. Main important features of the region can be listed up as below. These features are consistent with the features of the Baykit Arch.

1) Most of hydrocarbons concentrate on the small crest area of uplift features on the crystalline basement highs.
2) Most of the fields have extremely high helium content, ranging from 0.20 to 0.60 percent.
3) Oils and gases are emplaced in the oldest age reservoir rocks in the world[11)].
4) Oils are contained in fractures of the oldest rocks.
5) Some faults have significant vertical throw of displacement across the surface of the crystalline basement and these faults may have controlled the processes of oil and gas accumulation.
6) Oils were also produced from weathering basement crust (at the top of the basement).

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11) The world oil reserves are mainly emplaced in the Jurassic, the Cretaceous and the Tertiary formations (200-1 Ma), which are much younger than that of the East Siberia.

7) The oil-bearing horizons are thin, poor in horizontal continuity (pinch out), and formed stratigraphic traps. In such geological conditions, long distance oil migration is not likely to occur.

5.2 Basement-high Crest Play

Based on the above-mentioned characteristics, the author proposes in this report the following possibilities on oil migration mechanism in the East Siberian region. In this report, this proposed geological model is named "**Basement High Crest Play**".

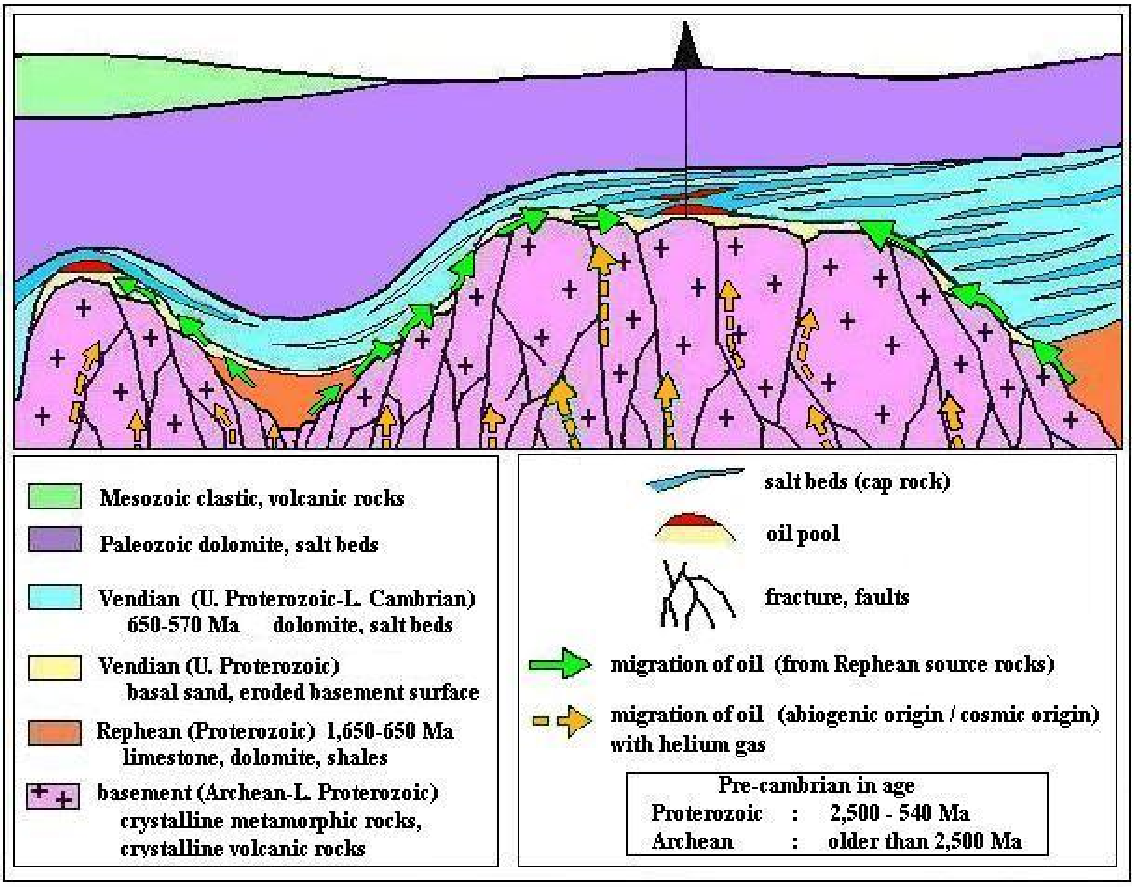
The surface of crystalline basement is bounded with unconformity to the overlain sedimentary formations. Generally, unconformity is a widely continuous plane (erosion surface), and it contains relatively high permeability compared to the massive rocks. Therefore, migrated oils from the depth might have passed through tiny space of the unconformity and reached to the crest position of the basement high (see Fig. 6). Oils have once accumulated in the crust of the weathering of the basement, and have been permeated upward to the sandstone layers or dolomite formations through fractures or faults. Consequently, oils have been confined in sands or fractures of carbonates as stratigraphic traps.

5.3 Origin of Oil and Gas in the East Siberian Region

Petroleum source rocks have not been identified yet. Although prolific source rocks of the Riphean are expected, the Riphean itself is absent in the most prolific region, the Nepa-Botuoba Arch. Matured source rocks of the Riphean are possible to be seated in the bottom of the basement depression areas on the Siberian platform. In that case, however, an unlikely process of long distance (more than several hundred kilometers) lateral or horizontal migration of huge amount of oil through low permeable rocks must be assumed. Such process is not likely to occur.

On the basis of these geological circumstantial evidences, the author considers that the following idea should be taken into account with respect to the origin of oils in the East Siberian region; 1) hydrocarbons generated by inorganic process in the depth, or 2) cosmic origin hydrocarbons that were incorporated during the Earth's early days, have migrated through basement fractures accompanying with helium gas [12)].

[12)] Thomas Gold (1987): Power from the Earth, translated into Japanese by H. Wakita in 1988.



Source: The Institute of Energy Economics, Japan (IEEJ)

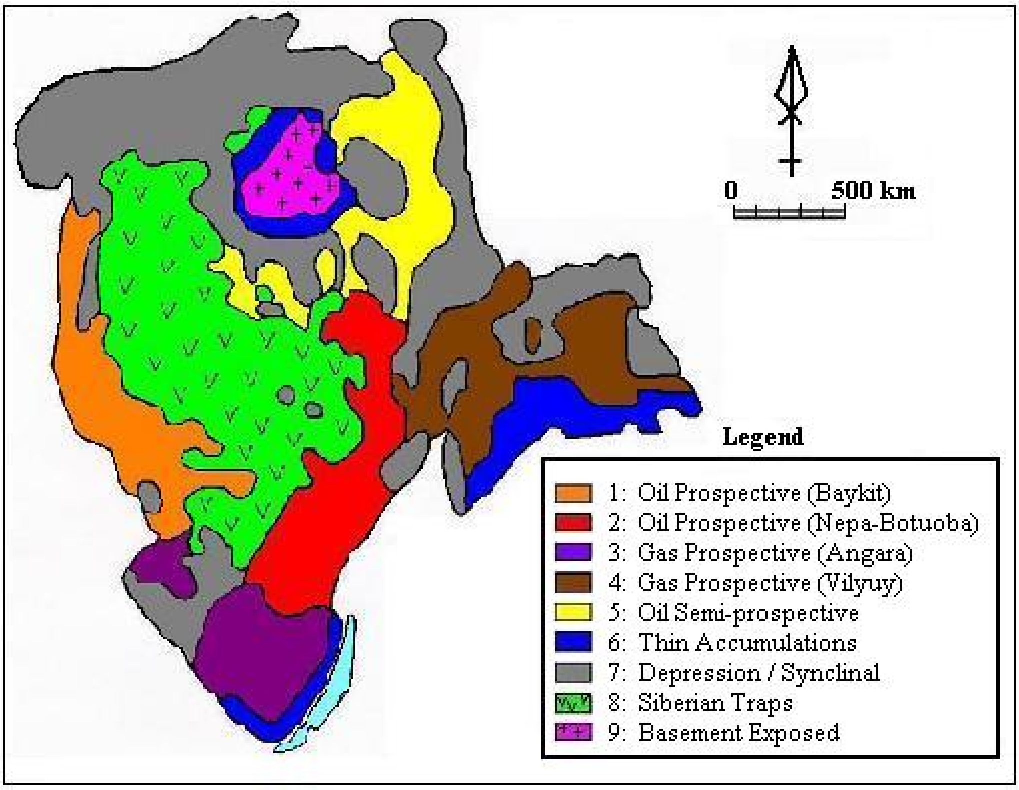
Fig. 6 Schematic Cross Section through the Basement-high Structures
(Oil and gas migration path on "Basement-high Crest Play")

6. Petroleum Resource Estimation of the East Siberia

The author has conducted petroleum resource estimation in the East Siberian region. The estimations have been carried out by "Barrel/Acre-feet method" based on the following assumptions; 1) "Basement-high Crest Play" is the main play-type for exploration in the Siberian platform area, and 2) inter-bedding anticlinal structures are exploration targets in the surrounding depression areas.

6.1 Classification of Geological Sub-provinces

Firstly, the author has classified the entire East Siberian region into nine geological sub-areas (see Fig. 7), based on the geological settings; 1) lithological distribution, 2) top horizon feature of the gravity basement-high, etc. referring to the geological maps [13].



Source: The Institute of Energy Economics, Japan (IEEJ) original

Fig. 7 Distribution Map of the Geological Sub-areas: East Siberia

The two most prospective areas of **1: Baykit Arch** and **2: Nepa-Botuoba Arch** can be demarcated based on the distribution of the existing oil and gas fields. The author extracted the extended basement-high area to the further north of the Nepa-Botuoba Arch as **3: Oil Semi-prospective Area**. The Angara-Lena Terrace province contains Koviktinskoye gas fields and small sized gas fields, and the Vilyuy Synclinal Province (basin) contains a series of gas fields along *an anticlinal feature named Khapchagay uplift* [14] developed in the center of the Viluy Basin. These areas are named as **Gas Prospective Areas (4: Angara, 5: Vilyuy)**. The other depression areas surrounding the Siberian platform are grouped as **7: Depression/Synclinal Area**. Some small-sized oil and gas fields have been discovered along the anticlinal features developed in Lena

[13] A) 1:5,000,000 in scale (Mineral Resources Map of Soviet Union, compiled by Metal Mining Agency Japan, 1987), B) 1:2,500,000 in scale (Tectonic Map of Oil and Gas Fields in Soviet Union, 1970).

[14] Motomura. Masumi (1980), Geology and hydrocarbon Potential of Siberian Platform (Vol.2); "Lena-Vilyuy and Yenisey-Khatanga Regions" (in Japanese), Journal of Oil Development, Japan National Oil Cooperation, Dec. 1980.

Anabar Fold Zone of Yenisey-Khatanga Basin located on northeastern part of the **Area 7**. The crystalline basement rocks are exposed on the top of the Anabar Arch. The author follows the widely accepted idea that the basement rock exposed area has least chance for oil and gas accumulation due to lack of a seal, and demarcates as **9: Basement Exposed Area**. The surrounding of the basement rocks exposed area has thin sedimentary rocks. The thin sedimentary areas in which thickness of deposits is less than 1,000 meters, is demarcated as **8: Thin Accumulations Area**. The thin deposited area also distributes along the igneous rocks exposed zone in the southeastern edge of the Siberian platform. Finally, the author extracted a geologically unique area named **6: Siberian Traps Area** distributing in northwestern part of the Siberian platform referring to the geological map (see Fig. 7).

<Siberian Traps>

It is known that the biggest extinction of 97 percent of all species of the Earth occurred due to the catastrophic environmental change (anoxia event) at age of P-T boundary (the boundary between Permian of late Paleozoic and Triassic of early Mesozoic, 250 Ma). The most promised theory is “meteorite or comet impact” same as the K-T boundary (the boundary between Mesozoic and Cenozoic) (Powell, 1998) [15)]. Recently, the sensational news were announced world-wide that the impact crater was found offshore Northwestern Australia in the sedimentary layers between the Permian and the Triassic, as an evidence of meteorite impact at 250 Ma in age [16)].

Associated with the catastrophic event during the P-T boundary, faulting was active and subsequently the West Siberian region began to subside. At the same time, basalt and dolerite began to flow out and covered the entire surface of the East Siberian region. Dolerite sills also have intruded into the sedimentary layers in western, central and northwestern part of the Siberian platform. A thickness of the dolerite sill varies several hundred meters to one thousand meters. *The lava flow and sills are often referred to by the generalized name of “Siberian Traps”* (Nolivkin, 1962) [17)]. At present, the Siberian Traps remain over the northwestern area of the Siberian platform, which has been remained from erosion and weathering.

In the areas covered by the Siberian Traps, seismic survey does not work due to disturbance

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15) Powell, J.L. (1998):Night Comes to the Cretaceous, translated into Japanese by Terashima T. and Setoguchi T. (2001), 373 pages.

16) Becker L., Poreda J., Basu R., Pope O., Harrison M., Nicholson C., Iasky R. (2004): A Possible End-Permian Impact Crater Offshore of Norhtwestern Australia, Science Express Research Articles (source: MSNBC News, May 13, 2004: Scientists find suspect in “Great Dying” impact, Did cosmic impact near Australia spark extinction?)

17) Nalivkin D.V. (1962):The Geology of the U.S.S.R., translated into English by Tomkeieff, Pergamon Press, p18-38.

and prevention of seismic wave to penetrate under the dolerite sills. Even if the hydrocarbon potential is high, seismic surveys over **6: Siberian Traps Area** could be impossible by current technology.

6.2 Expected Discovery Ratio for Oil and Gas

On the evaluation of hydrocarbon resources in East Siberian region, a concept of "expected discovery ratio for oil and gas (EDR)" is adopted. The EDR and hydrocarbon resources of each geological sub-area are calculated by the following formula;

EDR (Expected Discovery Ratio) = A / B

Where:

A: Total of the Known Recoverable Reserves (converted to C1+C2 equivalent)

B: Explored Area of the Sub-area (km^2)

Estimated Hydrocarbon Resources = EDR × C × D × E

Where:

C: Ratio of Explore-able Area (%)

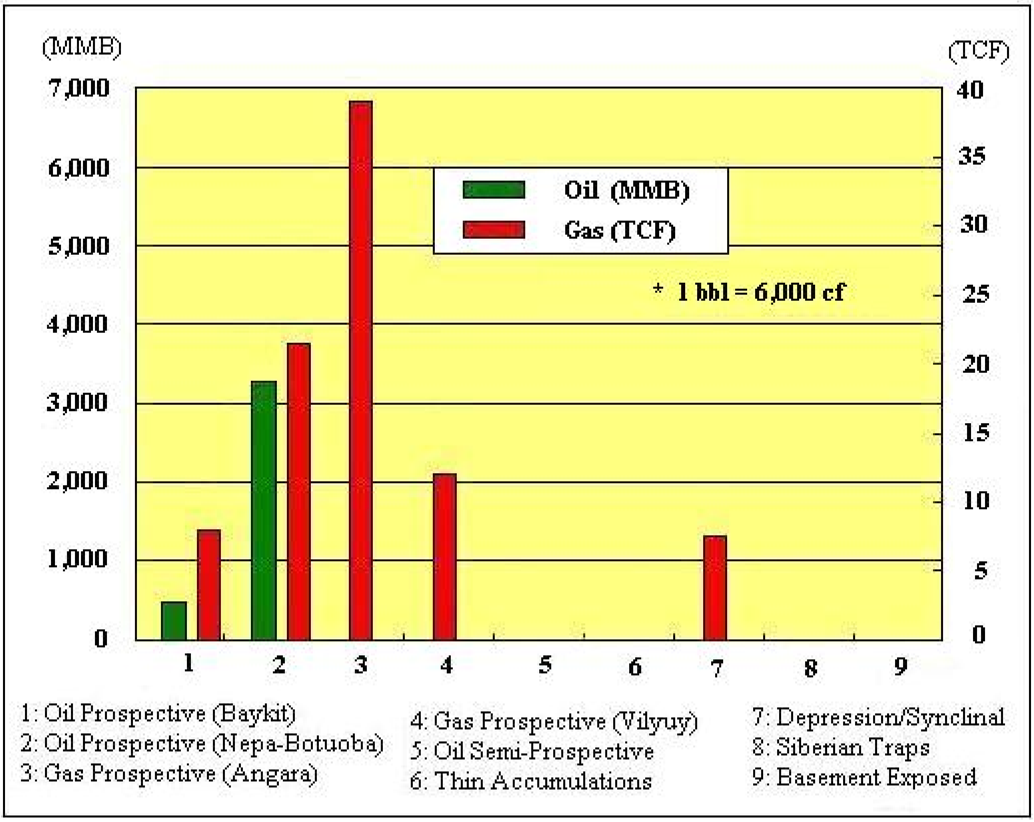
D: Distribution Ratio of Horst/Arch or Anticlinal Structures (%)

E: Total Area of Geological Sub-area (km^2)

The EDR is the parameter indicating how much of hydrocarbons (C1+C2 equivalent) can be expected to be found in a certain geological sub-unit based on the existing discoveries as the results of explorations.

<A: Total of Known Reserves (converted to C1+C2 equivalent)>

Current P50 reserves (in the Western definition, IHSE) of oil and gas fields in East Siberian region is shown in Fig. 8. The oil reserves are concentrated on both of the **Oil Prospective Areas (1: Baykit and 2: Nepa-Botuoba)**. The gas reserves are concentrated on **4: Angara Area** and some are distributed in **5: Vilyuy Area** and **7: Depression/Synclinal Area**.



Source: The Institute of Energy Economics, Japan (IEEJ) drafted from data of IHS Energy etc.

Fig. 8 Known Reserves (P50, proved plus part-probable) Distribution in the East Siberian Region

The target in this resource estimation is not to grasp the amount of exploitable reserves under current technologies but the geological inherent potential for petroleum in the East Siberian region. For this purpose, "C1+C2 equivalent reserves" (geologically justified and inferred reserves, P50 case in probabilistic methods of IHSE, or technically-recoverable resources in USGS' definition) was adopted. The "C1+C2 equivalent reserves" were calculated by the following formula:

C1+C2 equivalent reserves = P50 reserves (Western definition)× R/W Ratio

Where:

R : C1+C2 reserves (in Russian definition) in total of the largest five fields.

W: P50 reserves (in the Western definition) in total of the largest five fields.

The largest five oilfields and the largest gasfields are selected for the calculation of the R/W Ratio (the ratio of "C1+C2 reserves in Russian definition" to "P50 Reserves in the Western definition"), since the largest fields' reserves are evaluated to a considerable extent by the data of numerous drilling wells as compared with small discoveries. The difference between **R** and **W** is caused mainly by the difference of definition itself. Therefore, the R/W Ratio should be a constant value inherently in well-evaluated fields. In fact, the Russian estimated reserves in A+B+C1 category are close to the Western estimated P50 reserves (see Table 1).

Table 4 A Comparison of the Total Reserves of the Largest Five Oil/Gas Fields
The Western Definition vs. The Russian Definition

	Western Definition (P50 Reserves)*	Russian Definition （C1+C2） **	**R/W Ratio （Russian/Western）**
Largest Five Oil Fields Total Oil Reserves (MMBO)	3,381.2	5,928.1	**1.75**
Largest Five Gas Fields Total Gas Reserves（TCF）	56.1	137.6	**2.45**

* IHS Energy (2002)

** Ministry of Natural Resources of RF, Moscow, 2001 (in Russian), quoted from "Energy Systems Institute (2002), Study on Natural Gas Trade in Northeast Asia Sub-region, 143 pages"

<B: Explored Area>

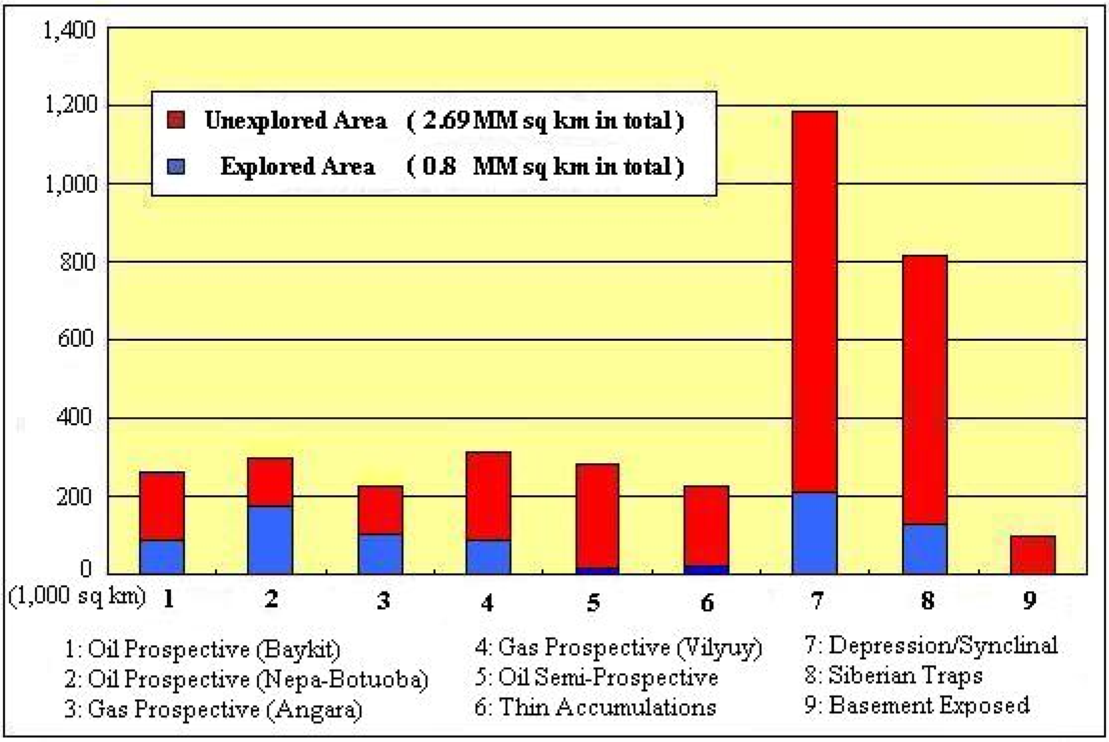
The author adopted a well density of "one well per 2,500 square kilometers" as the threshold between the explored area and the unexplored area based on the fact that the oil pool of the largest oil fields greater than one billion barrel of recoverable oil reserves (P50) extends to greater than 2,500 square kilometers. In other words, if an area of 50 kilometers by 50 kilometers wide has been drilled by greater than one exploratory well, such area can be regarded as that exploration of an oilfield of billion-barrel class has been already tried.

According to the said threshold, the entire area of the East Siberian region can be divided into "explored area" of 0.8 million square kilometers (22 percent of the total area) and "unexplored area" of 2.9 million square kilometers. Fig. 9 shows that explored area is distributed mainly in **2: Nepa-Botuoba Area**, **7: Depression/Synclinal Area**, and **6: Siberian Traps Area**.

As compared to Fig. 8, it is obvious that discovered hydrocarbon reserves are not proportionally related with explored area. It suggests an unevenness of hydrocarbon's habitat in the East Siberian region.

<C: Ratio of Explore-able Area (%)>

The dolerite sills are distributed not only in the Siberian Traps but also in other sub-areas sporadically. Effective seismic survey is basically not available in such thick dolerite-covered area. Percent of dolerite-uncovered area is extracted referring to geological maps and is allocated to each sub-area as "Ratio of Explore-able Area". The author also allotted suitable low percents as "Ratio of Explore-able Area" to some sub-areas where sedimentary rocks are thin.



Source: The Institute of Energy Economics, Japan (IEEJ) drafted from data of IHSE etc.

Fig. 9 The Explored Area vs. The Unexplored Area

<D: Distribution Ratio of Horst/Arch or Anticlinal Structures (%)>

The "Basement-high Crest Play" concept is applied to the Siberian platform area. Distribution ratio of basement-high is allotted to each sub-area, based on configurations of the basement top horizon. Some suitable percents in terms of the chance of forming anticlinal structures are allotted in depression/basin areas based on the fact [14] that hydrocarbons have been found only in localized anticlinal structures in Vilyuy and Khatanga basins.

6.3 Estimation Results

Based on the above-introduced parameters and assumptions, petroleum resources in the East Siberian region is calculated as shown in Table 5. The total hydrocarbon resources are estimated as **18.9 BBO** and **386 TCF**. The results show that **Oil Prospective Areas (2:Nepa-Botuoba)** and **(1:Baykit)** have oil potential of 9.2 BBO in C1+C2 equivalent and 1.9 BBO in C1+C2 equivalent, respectively. As a new potential area, **5:Oil Semi-prospective Area** is estimated to have oil potential of 7.2 BBO in C1+C2 equivalent. The sum of these three sub-area's estimated oil resources share 97 percent of the total estimated oil resources.

Table 5 Estimation Results of Petroleum Resources in the East Siberian Region (Standard Case)

Geological Sub-areas	Parameters for EDR*		Parameters for Resource Estimation					Estimated Hydrocarbon Resources
	Reserves P50 x 1.75 (oil) P50 x 2.45 (gas)	Explored Area (sq km)	EDR for Oil (MMB/sq km)	EDR for Gas (TCF/sq km)	Explore-able (%)	Horst/Dome Distribution (%)	Total Area (sq km)	Oil (MMBO) Gas (TCF)
Oil Prospective (Baykit)	Oil 822.5 MMB Gas 19.6 TCF	90,000	0.00913	0.00021	70	100	260,000	1,908 44
Oil Prospective (Nepa-Botuoba)	Oil 5,775.0 MMB Gas 51.5 TCF	170,000	0.03371	0.00031	85	100	292,500	9,240 84
Gas Prospective (Angara)	Gas 95.6 TCF	102,500	0.00091	0.00093	100	20	225,500	22 118
Gas Prospective (Vilyuy)	Gas 29.4 TCF	85,000	0.00091	0.00034	100	10	312,500	21 37
Oil Semi-prospective	none	7,500	0.03371	0.00031	100	80	275,000	7,214 66
Thin Accumulations	none	15,000	0.00913	0.00009	5	30	225,000	29 <1
Depression/Synclinal	Gas 19.6 TCF	207,500	0.00091	0.00009	100	10	1,185,000	89 27
Siberian Traps	none	122,500	0.03371	0.00093	5	30	812,500	349 10
Basement Exposed	none	0	0.00913	0.00093	0	10	97,500	<1 <1
Total, East Siberian Region	Oil 6,597.5 MMB Gas 215.7 TCF	800,000	* EDR : Expected Discovery Ratio				3,685,500	18,872 386

Source: The Institute of Energy Economics, Japan (IEEJ) original

Main exploration targets for new oilfield discoveries can be summarized as follows;

1) Unexplored fault-blocks in the vicinity of the existing large oilfields in both of the Nepa-Botuoba and the Baykit Areas.
2) Known basement horst/arch structures in both of the Nepa-Botuoba and the Baykit Areas, such as Nepa High, Kamov Arch and other basement-uplifts.
3) Undefined basement-high structures in the northern extended part of the Baykit Area.

4) Undefined basement-high structures in the Oil Semi-prospective Area which is to the north extended area of the Nepa-Botuoba Arch.

6.4 Up-side Potential

A huge unexplored area remains over the crest portion of the Baykit Arch. Therefore, the current reserves estimation, especially in C2 category (equivalent to probable plus part-possible reserves in the Western definition), varies in wide range. In fact, the Russian's estimated reserves of 7,030 MMBO in A+B+C1+C2 category (see Table 2) are significantly larger than one of the Western's figure of 2,979 MMBO [18]. In case that the Russian's estimated figure of 7,030 MMBO can be applied to the original estimation shown in Table 5, the EDR of the Baykit Arch is raised to 0.078 MMBO/km^2 from 0.00913 MMBO/km^2, and the estimated total oil resources of East Siberian region jump up to 67.2 BBO in C1+C2 equivalent (see Table 6). At present time, no reason is identified to deny the potential of the huge amount of hydrocarbon resources.

Table 6 Estimation Results of Petroleum Resources in East Siberian Region (Up-side Case)

Geological Sub-areas	Parameters for Resources Estimation				Estimated Oil Resources (MMBO)
	EDR for Oil (MMB/km^2)	Explore-able (%)	Horst/Dome Distribution (%)	Total Area (km^2)	
Oil Prospective (Baykit)	0.078	70	100	260,000	14,196
Oil Prospective (Nepa-Botuoba)	0.078	85	100	292,500	19,398
Gas Prospective (Angara)	0.078	100	20	225,500	3,518
Gas Prospective (Vilyuy)	0.078	100	10	312,500	2,430
Oil Semi-prospective	0.078	100	80	275,000	17,160
Thin Accumulations	0.078	5	30	225,000	263
Depression/Synclinal	0.078	100	10	1,185,000	9,243
Siberian Traps	0.078	5	30	812,500	951
Basement Exposed	0.078	0	10	97,500	0
Total, East Siberian Region	EDR : Expected Discovery Ratio			3,685,500	67,200

Source: The Institute of Energy Economics, Japan (IEEJ) original

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18) F5 of the USGS' estimation for undiscovered resources of Baykit Arch by probabilistic method. F5 represents a 5 percent chance of at least 2,979 MMBO, quoted from USGS(2001), Petroleum Geology and Resources of the Baykit High Province, East Siberia, Russia, USGS Web-site.

7. Conclusions

Estimated figures of the total oil resources ranging from **18.9 BBO** to **67.2 BBO** are obtained through the original resource estimations in the East Siberian region. These figures are equivalent to recoverable reserves of C1+C2 Russian category. Estimation results calculated by barrel/acre-feet method are usually expressed as reserves in-place, since the estimations are on the basis of oil-generation potential and oil-expel potential of assumed source rocks. But the author estimated resources in this time as recoverable reserves equivalent based on the known recoverable reserves of the existing fields. The estimated figures can also be expressed as **60 to 220 BBO in-place**, on assumption of 30 % of recovery factor.

The estimated figure of 18.9 BBO (recoverable) is equivalent to **88 million tons of supply-able amount of oil for 30 years**. This figure is rather conservative because the estimation parameter of EDR (expected discovery ratio for oil and gas) is based on the assumption that no additional discoveries will be made in the explored area. Even in the explored area, many of small and medium-sized oilfields with their area of oil pool not reaching the criteria of 50 km by 50 km, must be discovered in future. Recently, Mr. Leonard, Vice-President, Yukos Oil Corporation, presented their estimation results of **16.6 BBO** as risked recoverable reserves (sum of C1, C2 x 0.5, C3 x 0.25, D1 x 0.1) of oil potential in the East Siberian region at the Energy Seminars [19]. Although, both of the estimations are made based on different approaches, the outcomes are closely resembled.

The East Siberian region is not a sedimentary basin, instead a basement-uplifted area. Oil exploration activities in such geological settings have been extremely a rare case in the world. Since the most oil-prolific sedimentary basin is distributed west of the geological border, any successful case histories of oil exploration in the West Siberian Basin are not applicable straightly to the East Siberian region because of the totally different geological conditions. Moreover, source rocks and petroleum system have not been established yet in the East Siberian region. The author wonders that the present petroleum geological concept that has been accepted in the world may not be simply applicable for making sense of the petroleum existence in the East Siberian region.

With all such unique geological settings, Russians have continued their oil exploration in the East Siberian region and has drilled up to 1,000 wells in the Nepa-Botuoba Arch. The Arch

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[19] A presentation titled "Russian Oil Reserves, Production and Export Capacity" Ray Leonard, Vice President for Exploration and New Ventures, Yukos, in "Energy Seminars" held in Tokyo on June 17, 2004.

cannot be said as a frontier area of petroleum exploration anymore. Russians have already selected some prospective areas. It is obvious that a plenty of crude oil is emplaced even in the unusual old formations. The right of oil discoveries would be granted to only the challengers who bet on a chance of unique geological concept without sticking widely accepted conventional ides.

As mentioned above, the author believes that the existing oilfields in the East Siberian region can be explained by the newly proposed concept of "Basement-high Crest Play". On the basis of the new conceptual idea with geological circumstantial evidence, the author recommends the followings as the future prospective targets; 1) the known basement horst/arch structures such as Nepa-high, Kamov-arch and other basement-uplifts should be the primary exploration targets, 2) undefined basement-high structures in the northern part of the Baykit Area, the northern extended area of Nepa-Botuoba Arch and Oil Semi-prospective Area should be the secondary targets.

Significant crude oil production from fractures of granitic basement rocks (batholith or a part of craton in the geological term) interval has been verified recently in some basement high structures in offshore Vietnam [20) 21)]. A piece of unidentified information that *the existence of 80 oil and gas fields which occur partly or completely in crystalline basement rock in the west Siberian basin, including such as Yelley-Igai and Malo-Itchskoye fields from which all of the production of oil and gas occurs entirely and solely in the aforesaid rock from depths between 800-1,500 meters below the roof of the crystalline basement, respectively* (Professor Krayushkin, National Academy of Sciences of Ukraine) is also introduced on web-site [22)]. The petroleum system there is another argument on the basement play. As the number of successful cases increases relating to "Basement Play", and suppose that the evidence of hydrocarbon migration from the ultra-deep section of Earth's crust (abiogenic origin) is verified, not only sand/dolomite layers on the top of the basement but also the basement itself (fractures in the basement) would be regarded as oil exploration targets in the East Siberian region.

Upon completion of the pipeline linking the supply area (East Siberia) to the market in the Pacific region, oil exploration activities, including those of unconventional geological concept, will be accelerated in the East Siberian region. Various new and unique geological concepts will be evaluated. Subsequently, the additional oils derived from the new discoveries in the East Siberian

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20) A Japanese oil company, Japan Vietnam Petroleum, has produced crude oil from Randon Oilfield offshore Vietnam since 1998. The oil reservoir of the field is fractures in granitic basement (source: web-site of Nippon Oil).

21) SOCO Vietnam (UK) has discovered oil in the four prospects of granitic basement structures offshore Vietnam in 2002. Of which Ngua O-1X well successfully flowed crude oil of 330 b/d from only granitic basement rock interval of 389m. Ca NGU Vaug-aX well also successfully flowed crude oil of 3,100 b/d from only granitic basement rock interval of 850m (source: web-site of SOCO International).

22) Source: http://www.gasresources.net/VAKreplytBriggs.htm

region will fulfill the new pipeline and the East Siberian region may become a world-class huge oil-producing region. Should the pipeline plan be delayed, the development of the existing oilfields would be deterred considerably and the dormant huge oil resources underlying the East Siberian region could not be exploited without incentives for exploration.

Through the whole of human history, it can be said that the biggest chance of oil discoveries were only placed in the area where nobody had envisaged as prospective.

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