Available online at www.sciencedirect.com

ScienceDirect

RESEARCH PAPER

Distribution and potential of global oil and gas resources

TONG Xiaoguang[1, 2], ZHANG Guangya[1], WANG Zhaoming[1, *], WEN Zhixin[1], TIAN Zuoji[1], WANG Hongjun[1], MA Feng[1], WU Yiping[1]

1. Research Institute of Petroleum Exploration & Development, PetroChina, Beijing 100083, China;
2. China National Oil and Gas Exploration and Development Company Ltd., Beijing 100034, China

Abstract: Using conventional and unconventional oil and gas resource evaluation methods with play as a unit, this study evaluates the oil and gas geology and resource potential of conventional oil and gas resources and seven types of unconventional resources in the global major oil and gas basins (excluding China). For the first time, resource evaluation data with independent intellectual property rights has been obtained. According to evaluation and calculation, the global recoverable conventional oil resources are $5\,350.0\times10^8$ t, the recoverable condensate oil resources are 496.2×10^8 t, and the recoverable natural gas resources are 588.4×10^{12} m³. The remaining oil and gas 2P recoverable reserves are $4\,212.6\times10^8$ t, the reserve growth of oil and gas fields are $1\,531.7\times10^8$ t. The undiscovered oil and gas recoverable resources are $3\,065.5\times10^8$ t. The global unconventional oil recoverable resources are $4\,209.4\times10^8$ t and the unconventional natural gas recoverable resources are 195.4×10^{12} m³. The evaluation results show that the global conventional and unconventional oil and gas resources are still abundant.

Key words: global oil and gas bearing basins; resource evaluation; conventional oil and gas resources; oil and gas reserve growth; unconventional oil and gas resources

Introduction

In 2017, China's dependence on foreign oil was 67.4% and its dependence on foreign natural gas was 39%[1]. British Petroleum (BP) predicted that China's dependence on foreign oil and natural gas would be 76% and over 42% respectively in 2035[2]. The evaluation of global oil and gas geologic and resource potential is the basis for developing foreign oil and gas cooperation business. Major international oil companies and research institutes have carried out independent researches[3], but most of the research results are core information and are not open to the public. The U.S. Geological Survey (USGS) has carried out evaluations of oil and gas resources in some U.S. and global basins with petroleum system as evaluation unit, and has regularly released them to the public[4]. The International Energy Agency (IEA) publishes the energy outlook on a regular basis every year[5]. BP regularly updates the global oil and gas reserves, production and consumption status every year[6]. These data are the basis for analyzing the international oil and gas exploration potential and the oil and gas supply and demand, and making energy strategies.

Since 2008, relying on major national science and technology projects and major scientific and technological projects of China National Petroleum Corporation (CNPC), methods for the evaluation of conventional and unconventional oil and gas resources with play as unit have been innovated, and the oil and gas geologic and resource potential of conventional oil and gas resources and seven types of unconventional resources in major basins of the world except China have been assessed and the evaluation data with independent intellectual property rights have been obtained for the first time, which provides an important basis for decision-making of Chinese oil companies to "go overseas" and for the country to formulate energy strategies.

1. Evaluation methods

The global conventional oil and gas resources consist of four parts, namely, production, the remaining proved recoverable reserves, the recoverable reserves growth of discovered oil and gas fields, and the amount of undiscovered recoverable resources. In this paper, the production and the remaining recoverable reserves are mainly obtained through statistical analysis of data released by IHS Markit database[7–8]; the amount of undiscovered recoverable resources and the recoverable reserves growth of discovered oil and gas fields are mainly derived from the results of independent evaluation.

The evaluation of conventional oil and gas resources covers 425 basins and 678 plays in the world excluding China and basically includes all foreign oil-gas basins. The unconventional oil and gas resources evaluated mainly include tight oil (including shale oil), heavy oil, oil sands, oil shale, shale gas, tight gas and coal bed methane, and the evaluation includes 476 sets of layers in 363 basins in the world excluding China.

1.1. Evaluation methods for undiscovered conventional oil and gas resources

In the evaluation of undiscovered conventional oil and gas resources, play was taken as the basic evaluation unit[9–11]. Different evaluation methods were adopted based on different exploration maturities and different data available levels. The selection of parameters for all evaluation methods were based on comprehensive geological evaluation. For the evaluation units of high exploration maturity with more than 6 oil or gas fields discovered, the discovery process method was used for the evaluation. For the China National Petroleum Corporation Assets, trap summation method was adopted. For the evaluation units of medium exploration maturity with less than 6 oil and gas fields, subjective probability method based on geological analysis was used. Volumetric analogy method was used for evaluation units that did not have any oil or gas discoveries or had little data available. Finally, Monte Carlo simulation method was used to add and summarize the evaluation results of different evaluation units with different evaluation methods. The evaluation results were expressed in terms of probability. The confidence levels from high to low were 95%, 50%, 5% and Mean[10–12].

1.2. Evaluation methods for the conventional reserve growth of discovered oil and gas fields

The conventional reserve growth of discovered oil and gas fields refers to the newly-recovered conventional recoverable reserves in the entire life cycle of evaluation and development since the discovery of oil and gas fields due to appraisal, technological advances, changes in calculation methods, and political and economic factors. About 70% of the world's annual increase of conventional recoverable reserves comes from the reserves growth of discovered oil and gas fields [12-14]. Since 2P (Proved and Probable) reserve data of individual oil and gas fields in consecutive years cannot be obtained, it is difficult to establish a continuous reserve growth function based on an oil field. Therefore, the segmented cumulative multiplication method was used to obtain cumulative growth factors of different oil and gas fields over 30 consecutive years, and a model for oil and gas reserves growth was established (Fig. 1). The growth potential of discovered oil and gas fields in different regions were assessed by using their own reserve growth models[12]. This kind of evaluation is more reasonable. However, the USGS uses only the North American model to predict the reserve growth of the world[15], the reliability is poor.
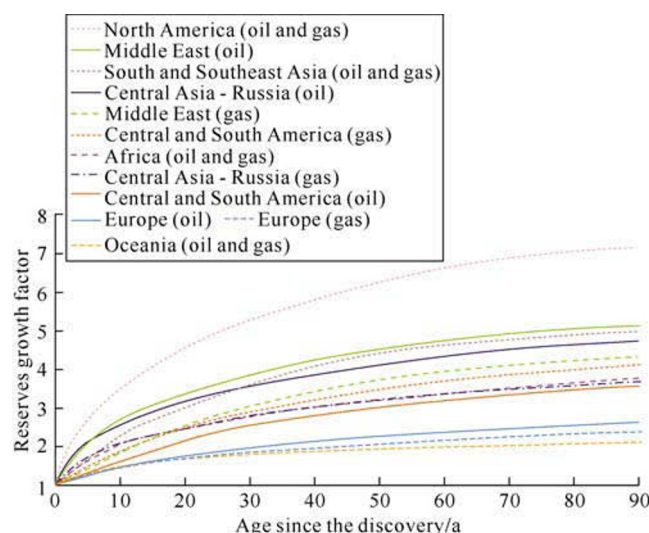

Fig. 1. Reserves growth curve of discovered oil and gas fields applicable to different regions.

1.3. Evaluation methods for unconventional oil and gas resources

In the evaluation of global unconventional oil and gas resources, basins were divided into basins for general evaluation, detailed evaluation and key evaluation based on the detailed level of basin data, resource types, maturity of exploration and development, evaluation requirements, and applicability of evaluation techniques. The parametric probability method, GIS (Geographic Information System) spatial graph interpolation method, genesis-constraint volume method and hyperbolic exponential decline method were used for evaluation. The basins for general evaluation are mostly basins with low maturity of exploration and development and a lack of basic data and basic maps, and they are uniformly evaluated by the parameter probability method. The basins for detailed evaluation are basins with exploration and development activities, rich basic geological data and little production data from production wells; the basins for key evaluation are basins with active exploration and commercial development, rich basic geological data, large scale of resources and detailed production data of production wells. For detailed evaluation and key evaluation basins with unconventional reservoir-controlled type, such as heavy oil, oil sands, oil shale, tight gas, and coal bed methane, GIS spatial graphic interpolation method was used for the evaluation. Besides, comprehensive evaluation should be performed for key evaluation basins based on the resource abundance, recoverability and economy to sort out favorable blocks. For detailed evaluation and key evaluation basins with mainly source-controlled resources such as tight oil and shale gas, genesis-constraint volume method was used for the evaluation. For key basins with a high maturity of exploration and development and detailed development data such as well production, the effective evaluation areas were determined using basic geological parameter mapping and evaluated by the hyperbolic exponential decline method, and finally the ultimate recovery of the favorable blocks was calculated[16].

2. Global conventional oil and gas resource potential

By the end of 2015, the world's cumulative oil production is $1\ 280.6 \times 10^8$ t, the proportion of oil and gas product is 23.9%; including cumulative condensate oil production 42.8×10^8 t, and cumulative natural gas production 62.9×10^{12} m^3[7–8]. The total amount of recoverable conventional oil and gas resources in the world is $10\ 727.9 \times 10^8$ t oil equivalent. The recoverable oil resources are mostly concentrated in the Middle East, Central Asia-Russia, and Central and South America, the amount in these areas are $3\ 853.9 \times 10^8$ t, accounting for 72.0%. Condensate oil was mainly concentrated in the Middle East and North America, the amount in these areas is 265.8×10^8 t, accounting for 53.6%. Recoverable natural gas resource are mainly concentrated in Central Asia - Russia and the Middle East, which are 354.4×10^{12} m^3, accounting for 60.2%.

The world's recoverable resources of conventional oil, condensate oil and natural gas are $5\ 350.0 \times 10^8$ t, 496.2×10^8 t, and 588.4×10^{12} m^3 respectively. The cumulative production of oil and gas are $1\ 918.2 \times 10^8$ t. The remaining recoverable 2P reserves of oil and gas are $4\ 212.6 \times 10^8$ t, accounting for 39.2% of the total. The recoverable reserves growth of discovered oil and gas fields is $1\ 531.7 \times 10^8$ t, accounting for 14.3% of the total. The amount of undiscovered recoverable oil and gas resources is $3\ 065.5 \times 10^8$ t, accounting for 28.6% of the total.

2.1. Remaining recoverable 2P reserves

The remaining recoverable 2P reserves of oil and gas are $4\ 212.6 \times 10^8$ t, of which oil reserves are $2\ 055.0 \times 10^8$ t, accounting for 48.8%; condensate oil reserves are 197.6×10^8 t, accounting for 4.7%; and natural gas reserves are 236.9×10^{12} m^3, accounting for 46.5%. They are mainly distributed in the Middle East (45.3%), followed by Central Asia - Russia (19.7%) and Central and South America (15.1%).

2.1.1. Distribution in different countries

The remaining recoverable 2P reserves of oil and gas are distributed in 82 countries (excluding China), among which Russia, Saudi Arabia, Iran, and Venezuela account for 14.4%, 12.4%, 11.8%, and 11.5% of the world total respectively. Oil is mainly concentrated in Saudi Arabia and Venezuela, accounting for 21.1% and 20.7% of the world respectively. Natural gas is mainly concentrated in Russia and Iran, accounting for 23.0% and 21.1% of the world total respectively (Fig. 2 and Table 1).

Russia's remaining recoverable 2P reserves of oil and gas are 572.4×10^8 t, of which oil reserves accounts for 29.8%, condensate oil reserves accounts for 3.8% and natural gas reserves accounts for 66.4%. The remaining recoverable 2P reserves of oil and gas in Saudi Arabia are 495.2×10^8 t, of which oil, condensate oil and natural gas account for 85.3%, 3.1% and 11.6% respectively. The remaining recoverable 2P reserves of oil and gas of Iran are 470.0×10^8 t, of which oil,
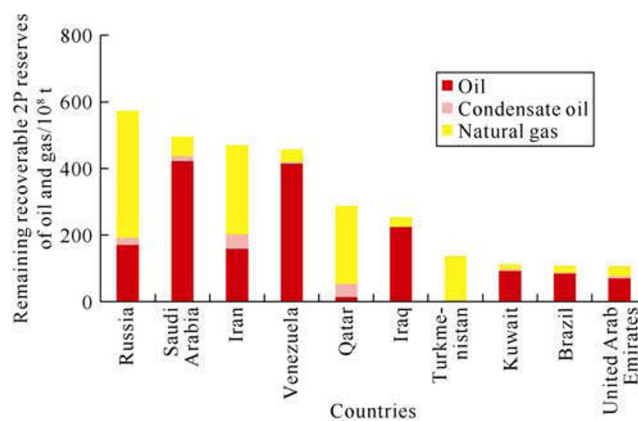

Fig. 2. Histogram of remaining recoverable 2P reserves of oil and gas in major countries.

Table 1. Statistics of remaining recoverable 2P reserves of oil and gas in major countries.

Countries	Remaining recoverable 2P reserves of oil and gas/10^8 t	Proportion of oil/%	Proportion of condensate oil/%	Proportion of natural gas/%
Russia	572.4	29.8	3.8	66.4
Saudi Arabia	495.2	85.3	3.1	11.6
Iran	470.0	33.9	9.0	57.1
Venezuela	456.8	90.8	0.9	8.3
Qatar	287.3	5.0	13.6	81.4
Iraq	253.9	88.4	0.5	11.1
Turkmenistan	136.5	2.0	1.1	96.9
Kuwait	111.3	83.3	5.1	11.6
Brazil	107.3	78.9	3.1	18.0
United Arab Emirates	105.6	66.9	6.6	26.5

condensate oil and natural gas account for 33.9%, 9.0% and 57.1% respectively. The remaining recoverable 2P reserves of oil and gas in Venezuela are 456.8×10^8 t, of which oil and natural gas occupy 90.8% and 8.3% respectively.

2.1.2. Distribution in basins

The remaining recoverable 2P reserves of oil and gas are mainly distributed in 38 basins (excluding China). The remaining recoverable 2P reserves of oil and gas in the Arabian Basin, the Eastern Venezuelan Basin, and the West Siberian Basin account for 58.9% of the total global remaining recoverable 2P reserves of oil and gas (Fig. 3 and Table 2).

The remaining recoverable 2P reserves of oil and gas in the Arabian Basin are $1\ 530.9 \times 10^8$ t, of which oil, condensate oil and natural gas reserves account for 53.1%, 6.4% and 40.5% respectively. The remaining recoverable 2P reserves of oil and gas in the eastern Venezuelan Basin are 412.6×10^8 t, of which oil, condensate oil and natural gas occupy 92.9%, 0.8% and 6.3% respectively. The remaining recoverable 2P reserves of oil and gas in the West Siberian Basin are 403.3×10^8 t, of which oil, condensate oil and natural gas take up 28.1%, 3.1% and 68.8% respectively.
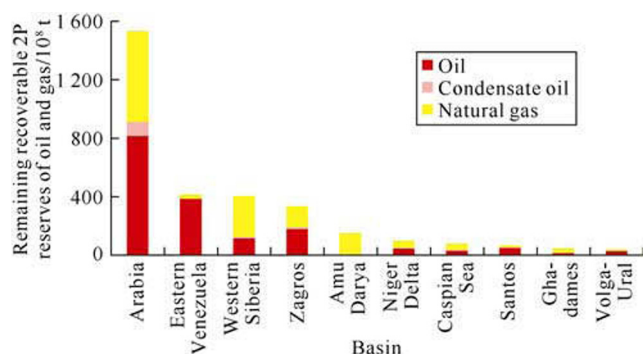
Fig. 3. Histogram of remaining recoverable 2P reserves of oil and gas in major basins.

Table 2. Statistics of remaining recoverable 2P reserves of oil and gas in major basins.

Basin	Remaining recoverable 2P reserves of oil and gas/10^8 t	Proportion of oil/%	Proportion of condensate oil/%	Proportion of natural gas/%
Arabian	1 530.9	53.1	6.4	40.5
Eastern Venezuelan	412.6	92.9	0.8	6.3
Western Siberian	403.3	28.1	3.1	68.8
Zagros	334.9	52.9	3.8	43.3
Amu Darya	148.6	0.7	1.7	97.6
Niger Delta	96.3	45.9	5.9	48.2
Precaspian	77.0	39.7	8.8	51.5
Santos	64.1	78.6	3.1	18.3
Ghadames	45.8	29.6	5.3	65.1
Volga-Ural	37.9	72.5	2.4	25.1

2.1.3. Distribution onshore and offshore

The remaining 2P recoverable oil and gas reserves of onshore are 2 371.6×10^8 t, of which oil, condensate oil and natural gas reserves are 1 136.0×10^8 t (accounting for 47.9%), 116.2×10^8 t (accounting for 4.9%) and 132.3×10^{12} m^3 (accounting for 47.2%) respectively. The remaining 2P recoverable oil and gas reserves of offshore are 1 840.9×10^8 t, of which oil, condensate oil and natural gas reserves are 854.2×10^8 t (accounting for 46.4 %), 97.6×10^8 t (accounting for 5.3 %) and 105.4×10^{12} m^3 (accounting for 48.3%). The remaining 2P recoverable reserves of onshore and offshore account for 56.3% and 43.7% of the total, respectively (Fig. 4).

2.1.4. Distribution in different lithology of reservoirs

The remaining 2P recoverable reserves of oil and gas in the world are mainly distributed in the reservoirs of clastic rock (52.1%) and carbonate rock (47.5%). The remaining 2P recoverable reserves of oil and gas in basement and other types of reservoirs account for only 0.4%.

The remaining 2P recoverable reserves in clastic reservoirs are 2 194.7×10^8 t, which are mainly distributed in 18 basins in eastern Venezuelan basin, Western Siberian and Arabian basin
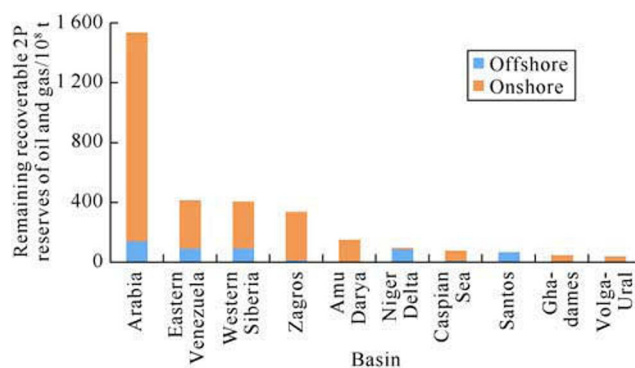

Fig. 4. Distribution histogram of remaining 2P recoverable oil and gas reserves onshore and offshore in major basins of the world.
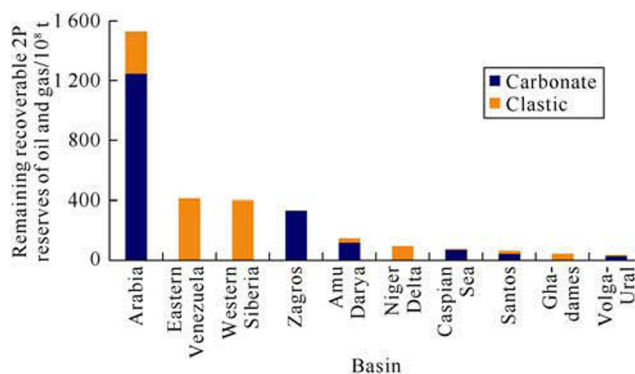

Fig. 5. Histogram of remaining recoverable 2P reserves of oil and gas in different lithology of major basins in the world.

(Fig. 5), of which oil, condensate oil and natural gas reserves account for 52.0%, 3.7% and 44.3%.

The remaining 2P recoverable reserves in carbonate reservoirs are 2 000.9×10^8 t, and are mainly distributed in 12 basins such as Arabia and Zagros (Fig. 5), of which oil, condensate and natural gas reserves account for 50.4%, 5.2% and 44.4% respectively.

2.2. Recoverable reserves growth potential of discovered oil and gas fields

In the next 30 years, the world's increase in recoverable reserves of discovered oil and gas fields will be 1 531.7×10^8 t, of which oil, condensate oil and natural gas reserves are 708.7×10^8 t (46.3%), 72.8×10^8 t (4.8%) and 90.5×10^{12} m^3 (48.9%) respectively. The reserves in the Middle East have the largest increase, accounting for 33.7% of the global total, followed by Central Asia-Russia and Africa, which account for 22.7% and 14.4% of the global total respectively. The reserves in Asia- Pacific, North America, Central Asia, and Central and South America have similar growth potential. The reserves in Europe have the lowest growth potential.

2.2.1. Distribution in different countries

Russia has the largest reserve growth potential in discovered oil and gas fields, accounting for 16.8% of the global total, of which the increase in oil reserves is 10.67×10^9 t, and the increase in natural gas reserves is 5.7% higher than that of

oil. Iran and Saudi Arabia have similar growth potential of oil and gas reserves, accounting for 10.0% and 9.8% of the global total, respectively. Qatar is dominated by the increase in natural gas reserves, accounting for 6.2% of the global total. The United States and Venezuela are dominated by the growth in oil reserves, accounting for 5.9% and 5.2% of the global total, respectively (Fig. 6 and Table 3).

The reserves growth of discovered oil and gas fields in Russia is $23.4×10^9$ t of equivalents, of which oil, condensate oil and natural gas reserves account for 45.6%, 3.1% and 51.3% respectively. The reserves growth of discovered oil and gas fields in Iran is $13.97×10^9$ t, of which oil, condensate oil and natural gas reserves account for 31.3%, 8.9% and 59.8%. The reserves growth of discovered oil and gas fields in Saudi Arabia is $13.68×10^9$ t, of which oil, condensate oil and natural gas reserves account for 75.4%, 4.7% and 19.9% respectively.

2.2.2. Distribution in different basins

The growth of global oil and gas field reserves mainly comes from the discovered oil and gas fields in 29 basins including Arabian Basin, West Siberian basin, Zagros Basin etc. The reserves growth of the Arabian Basin, Western Siberian Basin and Zagros Basin ranks the top three and the reserves growth of the three basins combined account for 42.1% of the global total (Fig. 7 and Table 4).
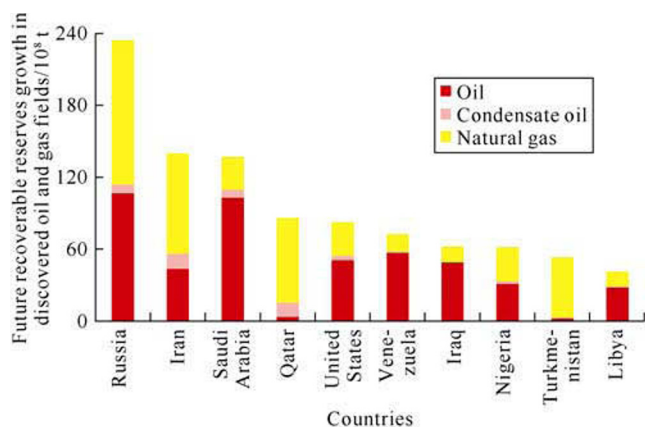
The reserves growth of discovered oil and gas fields in the Arabian Basin is $377.9×10^8$ t, of which oil, condensate oil and natural gas account for 49.9%, 7.7% and 42.4% respectively. The reserves growth of discovered oil and gas fields in the Western Siberian Basin is $154.6×10^8$ t, of which oil, condensate oil and natural gas take up 48.5%, 2.0% and 49.5% respectively. The reserves growth of discovered oil and gas fields in the Zagros Basin is $111.8×10^8$ t, of which oil, condensate oil and natural gas make up 49.6%, 5.4% and 45.0% respectively.

2.2.3. Distribution onshore and offshore

The reserves growth of onshore in the global land area is $909.9×10^8$ t, of which oil, condensate oil and natural gas make up 48.8%, 4.9% and 46.3% respectively. The reserves growth offshore is $621.8×10^8$ t, of which oil, condensate oil and natural gas account for 45.8%, 5.1% and 49.1% respectively. The reserves growths of onshore and offshore account for 59.4% and 40.6% of the total respectively, and the land area is still the main source of reserves growth (Fig. 8).

2.2.4. Distribution in different lithology of reservoir

The global reserves growth of discovered oil and gas fields

Fig. 6. Future recoverable reserves growth of discovered oil and gas fields in major countries of the world.
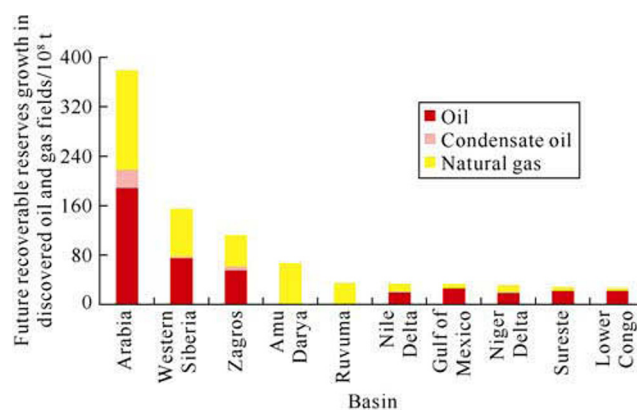

Fig. 7. Recoverable reserves growth of discovered oil and gas fields in major basins of the world.

Table 3. Statistics of future reserves growth of discovered oil and gas fields in major countries of the world.

Countries	Future reserves growth of discovered oil and gas fields/10^8 t	Proportion of oil/%	Proportion of condensate oil/%	Proportion of natural gas/%
Russia	234.0	45.6	3.1	51.3
Iran	139.7	31.3	8.9	59.8
Saudi Arabia	136.8	75.4	4.7	19.9
Qatar	86.1	4.5	13.4	82.1
United States	82.5	62.1	4.3	33.6
Venezuela	72.6	78.6	1.4	20.0
Iraq	62.0	78.9	0.6	20.5
Nigeria	61.7	50.7	3.5	45.8
Turkmenistan	53.4	4.6	1.3	94.1
Libya	41.6	68.3	2.1	29.6

Table 4. Statistics of future reserves growth of discovered oil and gas fields in major basins in the world.

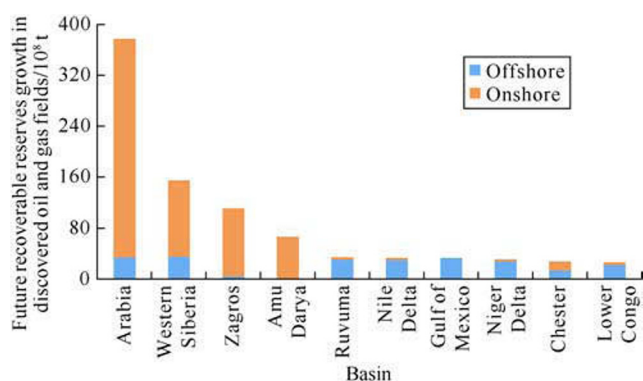| Basin	Future reserves growth of discovered oil and gas fields/10^8 t	Proportion of oil/%	Proportion of condensate oil/%	Proportion of natural gas/%
Arabian	377.9	49.9	7.7	42.4
Western Siberian	154.6	48.5	2.0	49.5
Zagros	111.8	49.6	5.4	45.0
Amu Darya	66.6	0.8	1.7	97.5
Ruvuma	34.5	0	1.4	98.6
Nile Delta	33.4	60.4	4.5	35.1
Gulf of Mexico	33.2	79.0	1.4	19.6
Niger Delta	31.4	60.3	4.5	35.2
Sureste	27.8	79.4	0.1	20.5
Lower Congo	26.3	84.7	0.6	14.7

Fig. 8. Histogram of distribution of future recoverable reserves growth of onshore or offshore in major basins of the world.

is distributed quite evenly in carbonate and clastic reservoirs, in which the reserves growth in clastic reservoirs accounts for 53.1%, the reserves growth in carbonate reservoirs accounts for 46.6%, the reserves growth in basement and other rocks accounts for about 0.3% (Fig. 9).

The global reserves growth of known clastic reservoirs is 813.4×10^8 t, of which oil, condensate oil and natural gas make up 53.1%, 4.7% and 42.2% respectively. It is mainly distributed in 13 basins including West Siberian Basin and Arabian Basin etc. The global reserves growth of carbonate reservoirs is 713.8×10^8 t, of which oil, condensate oil and natural gas occupy 51.3%, 6.1% and 42.6% respectively. It is mainly distributed in 10 basins, such as Zagros Basin and Amu Darya Basin etc.

2.3. Potential and distribution of undiscovered resources

The global undiscovered oil and gas resources are $3\ 065.5 \times 10^8$ t, of which oil, condensate oil and natural gas resources are $1\ 302.2 \times 10^8$ t (accounting for 42.5%), 181.0×10^8 t (accounting for 5.9%) and 191.1×10^{12} m^3 (accounting for 51.6%) respectively. They are mainly distributed in the Central Asia-Russia region (accounting for 26.6% of the global total), followed by the Middle East and Central and South America (accounting for 21.7% and 16.4% of the global total, respectively). The potential in Asia Pacific and Europe accounts for a low proportion.
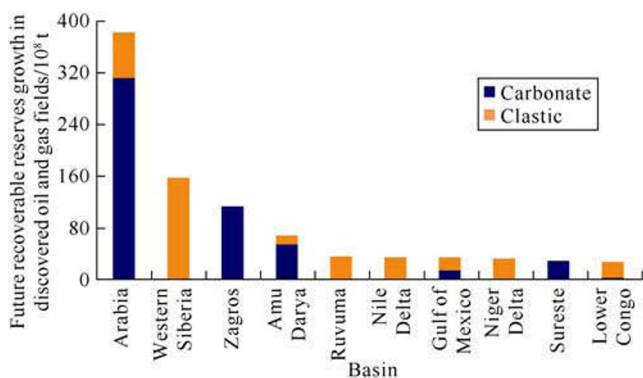

Fig. 9. Histogram of future recoverable reserves growth of discovered oil and gas fields in different lithologic reservoirs of major basins in the world.

2.3.1. Distribution in different countries

Russia has the largest potential of undiscovered resources (551.0×10^8 t), in which natural gas, oil and condensate oil account for 68.7%, 27.9% and 3.4% respectively. Venezuela ranks second with the potential of undiscovered resources of 327.9×10^8 t, in which oil, condensate oil and natural gas make up 82.2%, 1.0% and 16.8%, respectively. The United States has the potential of undiscovered resources of 266.6×10^8 t, in which oil, condensate oil and natural gas comprise 37.4%, 13.4% and 49.2% respectively (Fig. 10 and Table 5).

2.3.2. Distribution in different basins

The global undiscovered oil and gas resources are mainly distributed in 71 basins. The Arabia, Zagros and West Siberian basins rank the top three in terms of resource potential, and the amount of undiscovered resources in the three basins accounts for 29.4% of the global total (Fig. 11 and Table 6).

The undiscovered oil and gas resources in the Arabian Basin are 368.9×10^8 t, of which oil, condensate oil and natural gas make up 48.1%, 7.8% and 44.1% respectively. The undiscovered oil and gas resources in the Zagros Basin are 279.8×10^8 t, of which oil, condensate and natural gas comprise 42.5%, 5.8% and 51.7% respectively. The undiscovered oil and gas resources in the West Siberian Basin are 252.1×10^8 t,
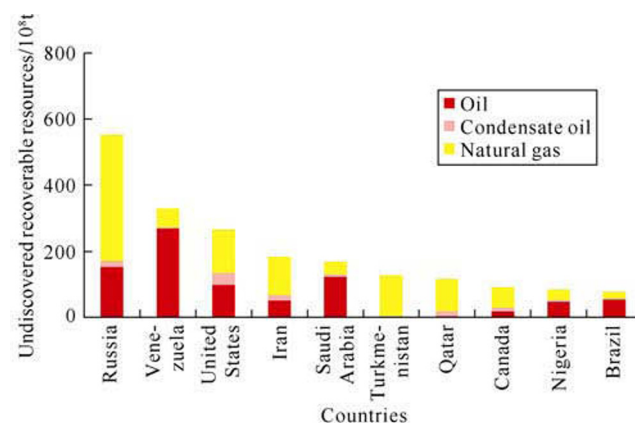

Fig. 10. Histogram of undiscovered oil and gas resources in major countries of the world.

Table 5. Statistics of undiscovered oil and gas resources in major countries of the world.

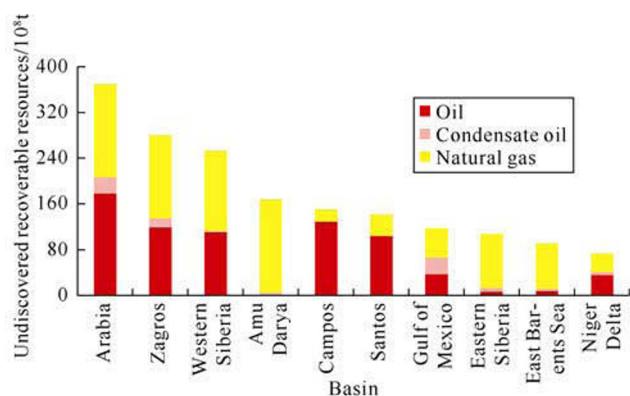| Countries	Undiscovered recoverable oil and gas resources/10^8 t	Proportion of oil/%	Proportion of condensate oil/%	Proportion of natural gas/%
Russia	551.0	27.9	3.4	68.7
Venezuela	327.9	82.2	1.0	16.8
United States	266.6	37.4	13.4	49.2
Iran	184.2	28.4	8.5	63.1
Saudi Arabia	169.1	72.8	4.7	22.5
Turkmenistan	128.2	2.8	1.1	96.1
Qatar	117.3	3.9	12.4	83.7
Canada	91.5	20.7	13.0	66.3
Nigeria	84.4	56.7	7.2	36.1
Brazil	78.0	70.9	2.8	26.3

Fig. 11. Histogram of undiscovered oil and gas resources in major basins of the world.

Table 6. Statistics of undiscovered oil and gas resources in major basins of the world.

Basin	Undiscovered recoverable oil and gas resources/10^8 t	Proportion of oil/%	Proportion of condensate oil/%	Proportion of natural gas/%
Arabia	368.9	48.1	7.8	44.1
Zagros	279.8	42.5	5.8	51.7
Western Siberia	252.1	43.8	1.1	55.1
Amu Darya	167.2	0.3	2.5	97.2
Campos	149.4	86.5	0	13.5
Santos	141.7	73.2	0.8	26.0
Deepwater in the Gulf of Mexico	117.7	31.9	24.2	43.9
Eastern Siberia	107.7	5.8	5.5	88.7
East Barents Sea	90.8	8.3	4.6	87.1
Niger Delta	73.0	48.5	7.2	44.3

of which oil, condensate oil and natural gas account for 43.8%, 1.1% and 55.1%.

2.3.3. Distribution onshore and offshore

The undiscovered oil and gas resources onshore are 1771.9 $\times 10^8$ t, of which oil, condensate oil and natural gas make up 47.8%, 5.0% and 47.2% respectively. The undiscovered oil and gas resources offshore are 1293.6$\times 10^8$ t, of which oil, condensate oil and natural gas comprise 45.6%, 5.1% and 49.3% respectively. The undiscovered oil and gas resources onshore and offshore account for 57.8% and 42.2% of the global total respectively (Fig. 12). The exploration potential of onshore conventional oil and gas resources is still huge, and the sea area is also an important reserve growth point in the future.

2.3.4. Distribution in different lithology of reservoir

The global undiscovered oil and gas resources in clastic reservoirs are slightly greater than those in carbonate reservoirs, accounting for 50.6% and 49.4% of the global total respectively. The amount of undiscovered oil and gas resources in carbonate reservoirs is 1 514.4$\times 10^8$ t, of which oil, condensate oil and natural gas account for 49.2%, 5.1% and 45.7% respectively. The undiscovered oil and gas resources in clastic reservoirs are 1 514.4$\times 10^8$ t, of which oil condensate
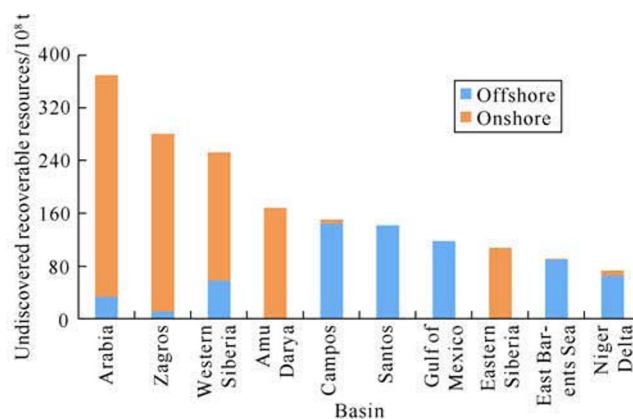

Fig. 12. Histogram of undiscovered oil and gas resources onshore and offshore in major basins of the world.
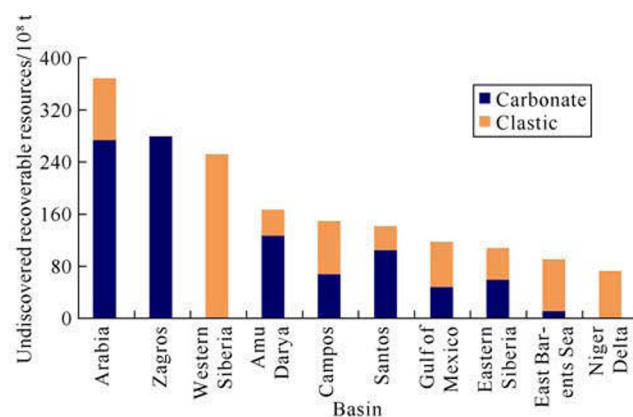

Fig. 13. Histogram of undiscovered oil and gas resources in different lithology of major basins in the world.

oil and natural gas make up 53.7%, 5.7% and 40.6% respectively (Fig. 13).

3. Unconventional oil and gas resources

The global unconventional oil and gas resources include seven types that have been commercially developed, i.e., heavy oil, oil sands, tight oil, oil shale, shale gas, coalbed methane (CBM), and tight gas. The recoverable unconventional oil and gas resources in the world are 5 833.5$\times 10^8$ t, of which unconventional oil are 4 209.4$\times 10^8$ t (accounting for 72.2%) and unconventional natural gas are 195.4$\times 10^{12}$ m^3 (accounting for 27.8%).

The global unconventional oil and gas resources are mainly distributed in 363 basins in 60 countries. The basins are mainly Foreland Basins, Craton Basins and Rift Basins. Unconventional oil and gas resources are most abundant in North America, where recoverable resources are 970.2$\times 10^8$ t, accounting for 33.8% of the world total; Central Asia-Russia in the second place has recoverable unconventional oil and gas resources of 1 262.2$\times 10^8$ t, accounting for 21.6% of the world total.

In global unconventional oil, oil shale has the largest amount of recoverable resources, which is 1 979.3$\times 10^8$ t, accounting for 47.0% of the total; heavy oil is in the second place, with recoverable resources of 1 248.5$\times 10^8$ t, accounting

for 29.7% of the total; oil sand takes the third place, with recoverable resources of 618.5×10^8 t, accounting for 14.7%; tight oil ranks the fourth, with recoverable resources of 363.2×10^8 t, accounting for 8.6%.

In global unconventional natural gas, shale gas has the largest amount of recoverable resources of 150×10^{12} m³, accounting for 76.7% of the global total; coalbed methane and tight gas with recoverable resources of 38.2×10^{12} m³ and 7.2×10^{12} m³ (accounting for 19.6% and 3.7%).

3.1. Regional distribution of recoverable unconventional oil and gas resources

3.1.1. Regional distribution of recoverable unconventional oil resources

About 73.4% of the world's recoverable unconventional oil resources are distributed in North America, Central Asia - Russia, and Central and South America. The recoverable resources in the North American region are $1\,502.0 \times 10^8$ t, accounting for 35.7% of the world's total, and dominated by oil shale, oil sands and heavy oil; The total recoverable resources in Central Asia-Russia are 960.9×10^8 t, accounting for 22.8% of the world's total, and are dominated by oil shale and oil sands. The total recoverable resources in Central and South America are 627.2×10^8 t, accounting for 14.9% of the world's total, and are dominated by heavy oil and oil shale.

Recoverable oil shale resources are mainly distributed in North America, Central Asia - Russia and Europe; heavy oil is mainly distributed in Central and South America, North America and the Middle East; oil sands are mainly distributed in North America and Central Asia - Russia; and tight oil is mainly distributed in North America, Central Asia - Russia and Central and South America (Fig. 14 and Table 7).

3.1.2. Regional distribution of recoverable unconventional natural gas resources

About 70.9% of the world's recoverable unconventional natural gas resources are enriched in North America, Central Asia - Russia, Asia Pacific, the Middle East. The recoverable resources in North America are 56.3×10^{12} m³, accounting for 28.8%, and are dominated by shale gas and coalbed methane. The recoverable resources in Central Asia-Russia are 36.3×10^{12} m³, accounting for 18.6%, and are dominated by

shale gas and coalbed methane. The recoverable resources in the Asia-Pacific region are 24.5×10^{12} m³, accounting for 12.5%, and are dominated by shale gas and coalbed methane. The recoverable resources in the Middle East are 21.4×10^{12} m³, accounting for 11.0%, and are dominated by shale gas.

The distribution of unconventional natural gas resources in the world is relatively balanced. Except that nearly half of the recoverable resources are enriched in North America and Central Asia-Russia, the recoverable resources in other regions all make up more than 9.6%. Shale gas is distributed in every major region, with recoverable resources of above 16.0×10^{12} m³ in each region. Coalbed methane is mainly concentrated in North America, Central Asia-Russia, and the Asia Pacific region. Tight gas is largely found in the North American region and rarely distributed in other major regions (Fig. 15 and Table 8).

3.2. Distribution of recoverable unconventional oil and gas resources in different countries and regions

3.2.1. Distribution of recoverable unconventional oil resources in different countries and regions

The global unconventional oil is distributed in 55 countries. More than 80% of the recoverable resources are concentrated in the United States, Russia, Canada, Venezuela, Saudi Arabia, Brazil, Ukraine, France and Mexico etc. The recoverable unconventional oil resources in the United States are 952.5×10^8 t, accounting for 22.6% of the global total, and are dominated by oil shale, heavy oil and tight oil. The recoverable resources
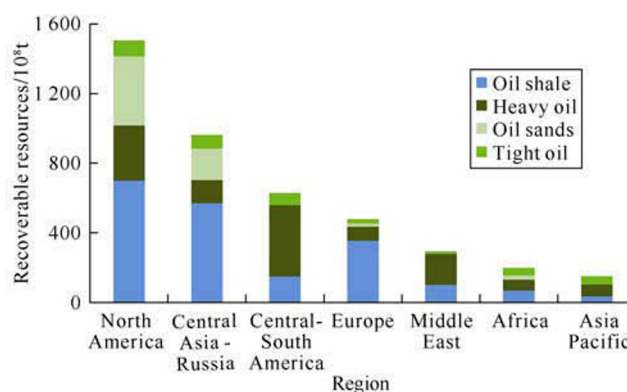

Fig. 14. Regional distribution of recoverable unconventional oil resources in the world.

Table 7. Statistics on regional distribution of recoverable unconventional oil resources in the world.

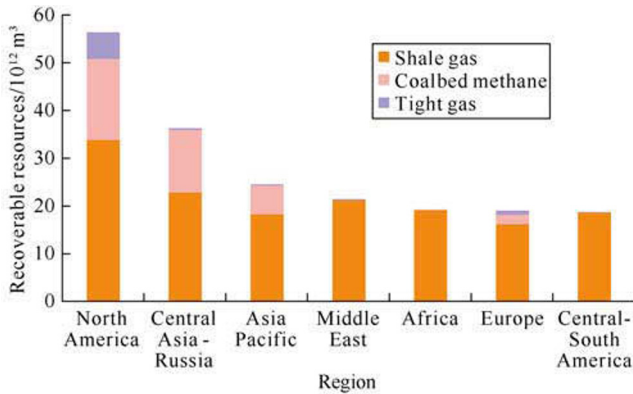| Region	Recoverable unconventional oil resources/10^8 t	Proportion of oil shale/%	Proportion of heavy oil/%	Proportion of oil sands/%	Proportion of tight oil/%
North America	1 502.0	46.5	21.2	26.3	6.0
Central Asia - Russia	960.9	59.4	13.7	18.9	8.0
Central-South America	627.2	23.9	65.2	0	10.9
Europe	479.5	73.8	17.2	3.7	5.3
Middle East	291.7	35.1	60.6	0	4.3
Africa	198.5	34.3	31.9	12.3	21.5
Asia Pacific	149.8	24.0	44.9	0	31.1
Total	4 209.4	47.0	29.7	14.7	8.6

Fig. 15. Regional distribution of recoverable unconventional natural gas resources in the world.

Table 8. Statistics on regional distribution of recoverable unconventional natural gas resources in the world.

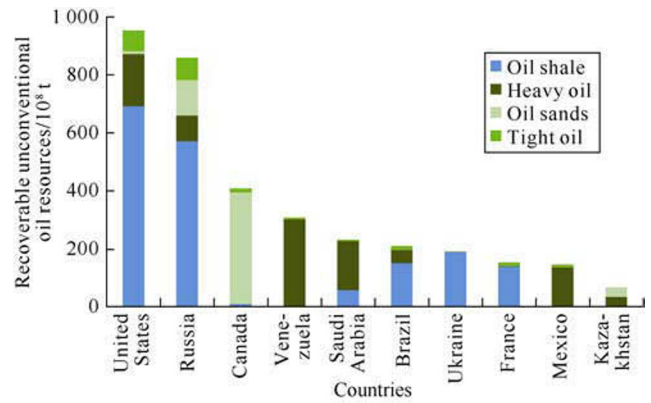| Region	Recoverable unconventional natural gas resources/10^{12} m³	Proportion of shale gas/%	Proportion of CBM/%	Proportion of tight gas/%
North America	56.3	60.1	30.2	9.7
Central Asia - Russia	36.3	62.8	36.2	1.0
Central-South America	18.8	99.0	0.2	0.8
Europe	19.0	85.3	10.7	4.0
Middle East	21.4	99.0	0	1.0
Africa	19.2	99.5	0.3	0.2
Asia Pacific	24.5	74.7	24.5	0.8

Fig. 16. Distribution of recoverable unconventional oil resources in major countries of the world.

Table 9. Statistics on recoverable unconventional oil resources in major countries of the world.

Countries	Recoverable unconventional oil resources/10^8 t	Proportion of oil shale/%	Proportion of heavy oil/%	Proportion of oil sands/%	Proportion of tight oil/%
United States	952.5	72.5	19.1	1.1	7.3
Russia	859.2	66.4	10.3	14.4	8.9
Canada	405.4	2.0	0	94.9	3.1
Venezuela	307.3	0	98.4	0	1.6
Saudi Arabia	230.7	24.2	73.7	0	2.1
Brazil	208.1	72.1	21.5	0	6.4
Ukraine	190.0	99.4	0	0	0.6
France	151.4	92.2	0.2	0.1	7.5
Mexico	144.1	92.2	0.2	0.1	7.5
Kazakhstan	66.3	92.2	0.2	0.1	7.5

in Russia are 859.2×10^8 t, accounting for 20.4% of the global total, and are dominated by oil shale, oil sand and heavy oil. The recoverable resources in Canada are 405.4×10^8 t, accounting for 9.6% of the global total, and are dominated by oil sands. The recoverable resources in Venezuela are 307.3×10^8 t, accounting for 7.3% of the global total, and are dominated by heavy oil.

Oil shale is mainly distributed in the United States, Russia, Ukraine, Brazil, and France. Heavy oil is mainly distributed in Venezuela, the United States, Saudi Arabia and Mexico. Oil sands are mainly distributed in Canada and Russia. Tight oil is mainly distributed in Russia, the United States and Canada (Fig. 16 and Table 9).

3.2.2. Distribution of recoverable unconventional natural gas resources in different countries and regions

The global unconventional natural gas is distributed in 38 countries. More than 80% of the recoverable resources are concentrated in 12 countries including the United States, Russia, Canada, Australia, Iran and Saudi Arabia. The recoverable resources in the United States are 39.5×10^{12} m³, accounting for 20.2% of the world total, where shale gas, coalbed methane and tight gas are all relatively rich. The recoverable resources in Russia are 28.5×10^{12} m³, accounting for 14.6% of the global total, and are dominated by shale gas and coalbed methane. The recoverable resources in Canada are 16.2×10^{12} m³, accounting for 8.3% of the global total, and are dominated by

coalbed methane and shale gas. The recoverable resources in Australia are 14.5×10^{12} m³, accounting for 7.4% of the global total, and are dominated by shale gas and coalbed methane.

The global unconventional natural gas resources are dominated by shale gas and coalbed methane. Shale gas is mainly distributed in the United States, Russia, Australia and Iran. Coalbed methane is mainly distributed in Russia, Canada, the United States and Australia. Tight gas is mainly distributed in the United States and Canada (Fig. 17 and Table 10).

3.3. Distribution of recoverable unconventional oil and gas resources in different basins

3.3.1. Distribution of recoverable unconventional oil resources in different basins

The global unconventional oil is mainly distributed in 134 basins. About 81.5% of the recoverable resources are distributed in 26 basins such as Alberta, Western Siberia, Volga-Ural, Piceance and Venezuela Basin. The recoverable resources in the Alberta Basin are 405.0×10^8 t, accounting for 9.6% of the world's total, and are dominated by oil sands and tight oils. The recoverable resources in the West Siberian Basin are 311.9×10^8 t, accounting for 7.4% of the world's total, and are dominated by oil shale and tight oil. The recoverable resources in the Volga-Ural Basin are 304.6×10^8 t, accounting
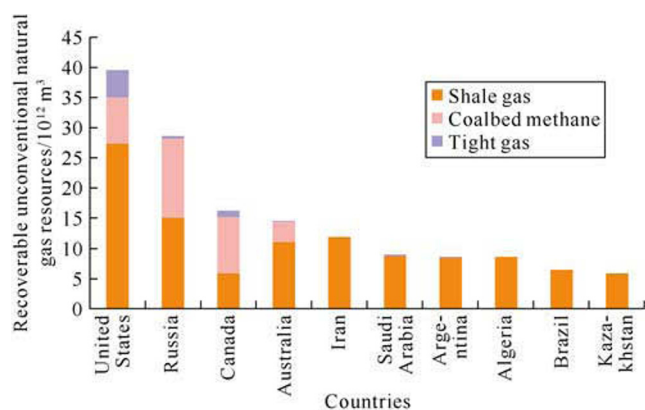
Fig. 17. Distribution of recoverable unconventional natural gas resources in major countries of the world.

Table 10. Statistics on recoverable unconventional natural gas resources in major countries of the world

Countries	Recoverable unconventional natural gas resources/10^{12} m³	Proportion of shale gas/%	Proportion of CBM/%	Proportion of tight gas/%
United States	39.5	69.2	19.6	11.3
Russia	28.5	52.8	46.0	1.2
Canada	16.2	36.3	57.5	6.2
Australia	14.5	76.3	23.0	0.7
Iran	11.9	100.0		
Saudi Arabia	9.0	97.6		2.4
Argentina	8.6	99.1		0.9
Algeria	8.6	100.0		
Brazil	6.5	99.7	0.3	
Kazakhstan	5.8	100.0		

for 7.2% of the world's total, and are dominated by oil shale and oil sands. The recoverable resources in the Piceance Basin are 300.6×10^8 t, accounting for 7.1% of the world, and are dominated by oil shale. The recoverable resources in the Eastern Venezuela Basin are 262.0×10^8 t, accounting for 6.2% of the world's total, and are dominated by heavy oil.

The global recoverable oil shale resources are mainly distributed in Piceance, Volga-Ural, Uinta and Western Siberian basin. The recoverable heavy oil resources are mainly distributed in eastern Venezuela, Central Arabian and West Siberian basins. The recoverable oil sand resources are mainly distributed in Alberta, East Siberia and Volga-Ural basins. The recoverable tight oil resources are mainly distributed in the West

Siberia, Alberta, and Paris basins (Fig. 18 and Table 11).

3.3.2. Distribution of recoverable unconventional natural gas resources in different basins

The global recoverable unconventional natural gas resources are distributed in 106 basins. About 80% of the recoverable resources are distributed in 26 basins. The recoverable resources in the Alberta Basin are 16.2×10^{12} m³, accounting for 8.3% of the world's total, and are dominated by coalbed methane, shale gas and tight gas. The recoverable resources in the Zagros Basin are 11.9×10^{12} m³, accounting for 6.1% of the world's total, and are dominated by shale gas. The recoverable resources in the Appalachian Basin are 11.5×10^{12} m³, accounting for 5.9% of the world's total, and are dominated by shale gas and tight gas. The recoverable resources in the East Siberian Basin are 10.3 ×10^{12} m³, accounting for 5.3% of the world's total, and are dominated by shale gas and coalbed methane. The recoverable resources in the US Gulf Basin are 9.8 ×10^{12} m³, accounting for 5.0% of the world's total, and are dominated by shale gas.

Global shale gas is mainly distributed in the Zagros, US Gulf Coast, Appalachian, and Ghadames basins. CBM is mainly distributed in Alberta, East Siberia, and Kuznetsk basins. Tight gas is mainly distributed in Alberta and Appalachian basins (Fig. 19 and Table 12).

4. Conclusions

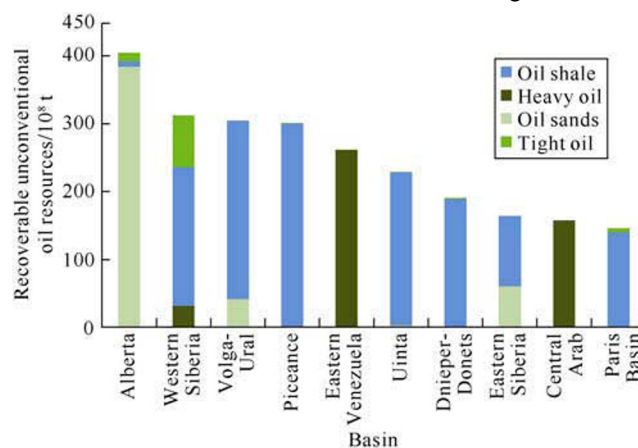The conventional and unconventional oil and gas resources

Fig. 18. Distribution of recoverable unconventional oil resources in major basins of the world.

Table 11. Statistics on recoverable unconventional oil resources in major basins of the world

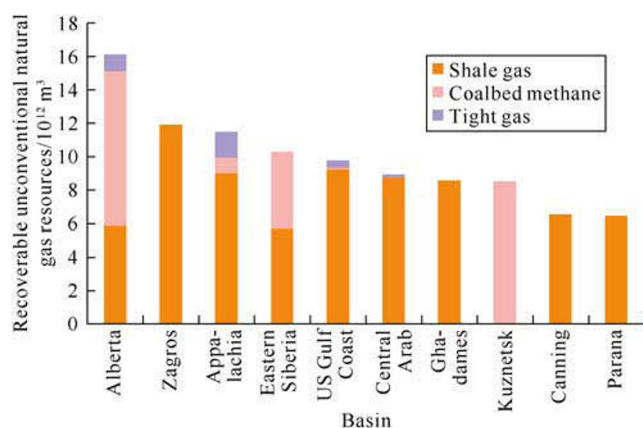| Basins	Recoverable unconventional oil resources/10^8 t	Proportion of oil shale/%	Proportion of heavy oil/%	Proportion of oil sands/%	Proportion of tight oil/%
Alberta	405.0	2.0		94.9	3.1
Western Siberian	311.9	65.6	10.2		24.2
Volga-Ural	304.6	86.4		13.6	
Piceance	300.6	99.9			0.1
Eastern Venezuela	262.0		99.5		0.5
Uinta	228.3	98.9		1.1	
Dnieper-Donets	190.0	99.4			0.6
Eastern Siberia	163.4	62.8		37.2	
Central Arab	156.8		100.0		
Paris Basin	145.3	96.1			3.9

Fig. 19. Distribution of recoverable unconventional natural gas resources in major basins of the world.

Table 12. Statistics on recoverable unconventional natural gas resources in major basins of the world.

Basin	Recoverable unconventional natural gas resources/10^{12} m^3	Proportion of shale gas/%	Proportion of CBM/%	Proportion of tight gas/%
Alberta	16.2	36.3	57.5	6.2
Zagros	11.9	100.0		
Appalachia	11.5	78.5	8.1	13.4
Eastern Siberia	10.3	55.2	44.8	
US Gulf Coast	9.8	94.5	1.1	4.4
Central Arab	8.9	98.0		2.0
Ghadames	8.6	100.0		
Kuznetsk	8.5		100.0	
Canning	6.5	100.0		
Parana	6.5	99.7	0.3	

evaluation method system with play as unit was used to complete the evaluation of conventional oil and gas resources for 678 plays of 425 basins and the evaluation of unconventional oil and gas resources for 476 play in 363 basins around the world excluding China. Unconventional oil and gas include tight oil, heavy oil, oil sands, oil shale, shale gas, tight gas, and coalbed methane. For the first time, we have got evaluation data with independent intellectual property rights, which can provide an important basis for "going overseas" decision-making of Chinese oil companies and for the country to formulate energy strategies.

The world's recoverable conventional oil resources are 5 350.0×10^8 t, the recoverable condensate oil resources are 496.2×10^8 t, and the recoverable natural gas resources are 588.4×10^{12} m^3. The cumulative production of oil and gas is 1 918.2×10^8 t, the proportion of production is 17.9%. The remaining recoverable 2P reserves of oil and gas are 4 212.6× 10^8 t, accounting for 39.2%, mainly distributed in Russia, Saudi Arabia, Iran, Venezuela etc. The reserves growth of discovered oil and gas fields is 1 531.7×10^8 t, accounting for 14.3%, mainly distributed in the Middle East, Central Asia - Russia, Africa and other regions. The undiscovered recoverable oil and gas resources are 3 065.5×10^8 t, accounting for 28.6%, mainly distributed in Russia, Venezuela, the United States.

The total amount of recoverable unconventional oil and gas resources in the world is 5 833.5×10^8 t. The recoverable un-

conventional oil resources were 4 209.4×10^8 t, accounting for 72.2%, mainly distributed in the United States, Russia, Canada, and Venezuela. The recoverable unconventional natural gas resources are 195.4×10^{12} m^3, accounting for 27.8%, mainly distributed in the United States, Russia, Canada and Australia. Due to technological advancement, unconventional oil and gas resources have become an effective supplement to conventional oil and gas resources. In particular, tight oil and gas resources have good economic benefit and are leading in a revolution in the oil and gas industry.

From a global perspective, conventional oil and gas resources are still abundant, and the development and utilization of unconventional oil and gas resources are just starting. Rational and effective use of oversea oil and gas resources is an inevitable way for China's economic development.

References

[1] CNPC Economics & Technology Research Institute. Oil and gas industry development report at home and abroad in 2017. Beijing: Petroleum Industry Press, 2017.

[2] BP. BP energy outlook: 2017 edition. (2017-12-20)[2018-02-10]. https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/energy-overview-the-base-case.html.

[3] AHLBRANDT T S, CHARPENTIER R R, KLETT T R, et al. Global resource estimates from total petroleum systems. Tulsa, Oklahoma: American Association of Petroleum Geologists, 2005.

[4] KLETT T R, GAUTIER D L, AHLBRANDT T S, et al. An evaluation of the U.S. Geological Survey world petroleum assessment 2000. AAPG Bulletin, 2005, 89(8): 1033–1042.

[5] IEA. World energy outlook 2017. (2017-09-20)[2018-02-12]. http://www.iea.org/weo2017/.

[6] BP. Statistical review of world energy. (2017-09-20) [2018-02-10]. https://www.bp.com/en/global/corporate/energy-economics/ statistical-review-of-world-energy.html.

[7] IHS Markit. IHS energy: EDIN. (2011-01-01)[2017- 12-31]. https://ihsmarkit.com/index.html.

[8] IHS MARKIT. IHS energy: Vangtage. (2011-01-01) [2017-12-31]. https://ihsmarkit.com/index.html.

[9] TONG Xiaoguang, ZHANG Guangya, WANG Zhaoming, et al. Global oil and gas potential and distribution. Earth Science Frontiers, 2014, 21(3): 1–9.

[10] TONG Xiaoguang, HE Dengfa. Principle and method of oil and gas exploration. Beijing: Petroleum Industry Press, 2001.

[11] TONG Xiaoguang, LI Haowu, XIAO Kunye, et al. Evaluation method for increase of reserves in large oil-gas fields based on reserves growth model & probability analysis and its application in Middle East. Acta Petrolei Sinica, 2009, 30(3): 317–323.

[12] WU Yiping, TIAN Zuoji, TONG Xiaoguang, et al. Evaluation method for increase of reserves in large oil-gas fields based on reserves growth model & probability analysis and its application in Middle East. Acta Petrolei Sinica, 2014, 35(3): 469–479.

[13] YU Gongming, XU Jianshan, TONG Xiaoguang, et al. Study on the reserve growth of known oil and gas fields in the world. Earth Science Frontiers, 2014, 21(3): 195–200.

[14] BIAN Haiguang, TIAN Zuoji, WU Yiping, et al. Reserve growth characteristics and potential of the discovered giant oil fields in the Middle East. Petroleum Exploration and Development, 2014, 41(2): 244–247.

[15] KLETT T R. United States Geological Survey's reserve: Growth models and their implementation. Natural Resources Research, 2005, 14(3): 249–264.

[16] WANG Hongjun, MA Feng, TONG Xiaoguang, et al. Assessment of global unconventional oil and gas resources. Petroleum Exploration and Development, 2016, 43(6): 850–862.