

# Characteristics and Trends of Deep Oil and Gas Research in China (1984-2024)

—Research from the Perspective of CiteSpace

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**How to cite this paper:** Liu, Z. C., & Shen, Y. X. (2024). Characteristics and Trends of Deep Oil and Gas Research in China (1984-2024). *Journal of Geoscience and Environment Protection*, 12, 255-276. <https://doi.org/10.4236/gep.2024.1210014>

**Received:** September 14, 2024

**Accepted:** October 28, 2024

**Published:** October 31 2024

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## Abstract

Deep oil and gas refer to oil and gas resources buried at a significant depth below the surface. Compared with conventional oil and gas, deep oil and gas often face more complex geological conditions and technological challenges, therefore, the development and exploitation of these oil and gas resources require advanced technology and equipment. Use bibliometrics to study academic literature. Select available data and download it in “RefWorks” format. Import the data into Cite Space 6.3.R2 software for author collaboration and keyword emergence analysis and visualization. Use Microsoft Excel 2016 software to analyze the annual publication volume, literature institutions, and disciplinary distribution of domestic and international scholarly literature. Research has found that: 1) The institution with the highest number of publications in the field of deep oil and gas in China is the China Petroleum Exploration and Development Research Institute; The author with the highest number of publications is Zhu Guangyou; The author with the highest citation frequency is Jia Chengzao; The research work in the field of deep oil and gas in China is mainly led by national level fund projects. 2) The research hot-spots of deep oil and gas in China are showing a trend of shifting from Jilin and Henan to Xinjiang and Sichuan. 3) The research on deep oil and gas fields in the Paleogene of China is mainly concentrated in Henan Province and Shandong Province. The Lower Tertiary, Cambrian and Jurassic are respectively concentrated in Dongpu Sag, Dongying Sag, Sichuan Basin, Tarim Basin in Xinjiang, the Junggar Basin and Qaidam Basin in Qinghai. The Sinian, Ordovician, Cretaceous, and Neogene systems are mainly concentrated in Sichuan, Xinjiang, and Qinghai provinces. The Permian system is mainly

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located in the southwest and Northwest of China. This article uses a new research perspective and methodology to systematically analyze the current situation and future development trends of deep oil and gas exploration and development in China, which is of great significance for promoting effective exploration and development of deep oil and gas resources.

## Keywords

Deep Oil and Gas, Citespace, Bibliometrics, Knowledge Graph

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## 1. Introduction

Deep oil and gas refer to oil and gas resources buried at a greater depth below the surface (Jia et al., 2016). Compared with conventional oil and gas, deep oil and gas usually face more complex geological conditions and technical challenges, so the development and exploitation of these oil and gas resources require advanced technology and equipment (Zhang et al., 2015). Deep oil and gas have three characteristics: 1) Large depth: deep oil and gas are usually buried at a depth of 3000 - 6000 meters or even deeper (Li et al., 2020). 2) High temperature and high pressure: with the increasing buried depth, the temperature and pressure of the formation show a significant upward trend, which puts forward higher requirements for drilling and production equipment (Tuo, 2002). 3) Complex geology: the geological structure of deep strata is more complex, and there may be faults, folds, etc. (Sun et al., 2024).

At present, the deep-seated oil and gas resources buried more than 4500 meters have become the key field of increasing reserves and production of global oil and gas resources, and its proven reserves account for 40% of the world's total reserves. In the past five years, China has performed particularly well in this field. The deep oil production has steadily increased from 121 million tons to 150 million tons, and deep natural gas production has also increased significantly from 105.4 billion cubic meters to 140 billion cubic meters. Since 2019, deep oil and gas exploration in Ordos, Junggar, Sichuan and other basins has made breakthroughs, and deep oil and gas has become another new unconventional oil and gas exploration field after shale gas. However, compared with the middle shallow part, the deep geology has the characteristics of deep drilling, high temperature, high pressure and high ground stress, and the adaptability of existing drilling technology and instruments and materials in extreme environments is limited, which leads to frequent complex accidents in the process of deep oil and gas drilling and significantly prolongs the drilling and completion cycle, which has become the key problem and challenge restricting the efficient development of deep oil and gas resources.

At present, there are many literatures on deep oil and gas, but there is a lack of sort and summary of these articles (Hou & Hu, 2013). By using CiteSpace to analyze the literature data in the field of deep oil and gas, researchers can systematically master the research hot-spots, key literatures, main authors and research institutions of deep oil and gas, as well as its development trend and frontier direction

(Chen et al., 2015). This not only contributes to academic research, but also provides a scientific basis for technology development and policy-making.

## 2. Materials and Methods

### 2.1. Data Sources

The data in this paper are selected from web of science and CNKI and retrieved using the keywords “deep hydrocarbon exploration” and “deep hydrocarbon”. The time range was set to “1984-2024”, and 4168 results were retrieved. Among them, there were 1018 results in Chinese literature, including 682 academic journals, 105 dissertations, 131 meeting minutes, 49 achievements and 46 reports, covering the period from 1984 to 2024; A total of 3150 results were obtained from international scholarly literature, including 2783 academic journals, 208 dissertations, 131 literature reviews, 125 monographs, 71 meeting minutes, etc., covering the period from 1978 to 2024.

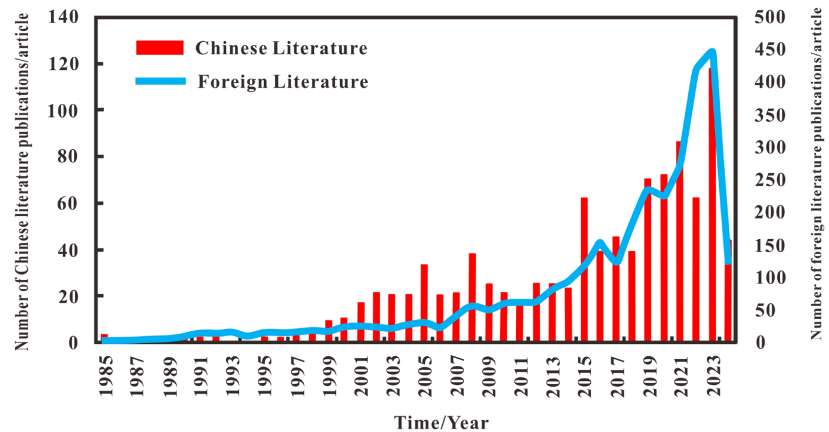
### 2.2. Method

Bibliometrics is a tool and technology that uses quantitative analysis and statistical methods to study academic literature. By analyzing the number, distribution and characteristics of literature, it reveals the dynamics, trends and laws of scientific research (Xiao et al., 2011). Select the available data and download it in “Ref-works” format. Import the data into cite space 6.3.r2 software to analyze and visualize the author’s cooperative relationship and keyword emergence. Microsoft Excel 2016 software was used to analyze the annual number of published literatures, literature institutions and subject distribution in China and abroad.

## 3. Research Results and Analysis

### 3.1. Number of Documents Issued

The time distribution of paper publication is an important window for insight into the research trends and hot-spot changes in a discipline (Bi et al., 2023). The retrieval results in CNKI and web of science show that a total of 4168 deep oil and gas literatures were published internationally from January 1984 to June 2024. It can be seen from **Figure 1** that the number of publications of both international and Chinese literatures has shown a significant upward trend. However, the number of papers published in global languages is three times that in Chinese. This may be because leading international technology for deep oil and gas exploration and development is relatively advanced, which usually means that research and development in related fields are earlier and more advanced. In addition, the advancement of technology may also attract more international cooperation and contributions, further promoting the number of papers published in global languages. The earliest period of deep oil and gas research was in the 1950s. Looking at the whole deep oil and gas field research, it can be roughly divided into three stages: preliminary exploration stage (1950-1977), breakthrough discovery stage (1997-2014) and scale development stage (2014 to now).



**Figure 1.** The trends in publications on deep oil and gas.

In the preliminary exploration stage (1950-1997), although China's deep oil and gas research started late on the whole, it does not mean that it is completely ignorant of deep oil and gas resources. From the perspective of literature records, the first article on deep oil and gas collected by CNKI can be regarded as a symbolic starting point for Chinese academia to formally get involved in this research field. It is an article published by Wang Xiepei in geological science and technology information in 1985. The research content is that Wang Xiepei's predecessor participated in the annual meeting of the American Association of petroleum geologists and discussed with International petroleum geologist that the oil and gas exploration in the coastal areas of the Gulf of Mexico will move towards the deep (Wang, 2023).

In the breakthrough discovery stage (1997-2014), with the continuous consolidation of the theoretical foundation and the continuous improvement of technical means in the field of deep oil and gas development in China, the research in this field has gradually stepped on the right track in China and made significant progress. At this stage, a total of 230 Chinese literatures on deep oil and gas research were published (10 by Yang Haijun, 9 by Jia Chengzao, 8 by Wang Xianbin, 7 by Tuo Jincai, 6 by Zhao Wenzhi, and 5 by Zhou Shixin). In 2005, the annual number of published papers reached a small peak, and a total of 23 papers were published. The nine years from 2006 to 2014 experienced a period of fluctuation, which showed the phenomenon of first falling and then rebounding and rising.

In the stage of large-scale development (from 2014 to now), the number of papers published is still rising steadily. In addition to the continuous development of the research direction in the stage of large-scale development, it also integrates with other disciplines, forming some research directions with characteristics and development prospects, such as the frontier Application Research of algorithm in deep oil and gas exploration and development.

### 3.2. Journal Distribution

Analyzing the amount of research results published in journals can become an effective indicator to measure and reflect the influence and importance of authoritative journals in an academic field (Han et al., 2016). The top 20 journals

published 381 papers, accounting for 54.44% of the total number of papers. Among the Chinese literature, the top five journals with the highest publication volume are “Acta Petroleum”, “Natural Gas Earth Science”, “Petroleum Exploration and Development”, “Petroleum Experimental Geology”, and “Natural Gas Industry”. The top five journals with the highest number of International scholarly literature publications are “Marine and Petroleum Geology”, “Journal of Petroleum Science and Engineering”, “Petroleum Exploration and Development”, “Frontiers in Earth Science”, and “AAPG Bulletin”.

It can be seen from **Table 1** that there is less literature on deep oil and gas research in China than in other countries, mainly published in “Acta petrological Sinica” and “Natural Gas Geoscience”, with 39 and 33 papers, accounting for 15.12% and 12.79% of the total. The journals with 26 - 30 papers are “petroleum exploration and development”, “petroleum experimental geology”, “natural gas industry” and “Chinese enterprises”, accounting for 10.85%, 10.46%, 10.46% and 10.08% of the total papers, respectively.

**Table 1.** Top 10 journals in terms of publication volume in both Chinese and English literature.

Serial Number	Chinese journal	Number of articles	Influencing factors*	Serial Number	English journal	Number of articles	Influencing factors*
1	Journal of Petroleum	39	5.762	1	Marine and Petroleum Geology	339	4.2
2	Natural Gas Earth Science	33	2.768	2	Journal of Petroleum Science and Engineering	139	4.536
3	Petroleum Exploration and Development	28	9.228	3	Petroleum Exploration and Development	100	7.5
4	Petroleum Experimental Geology	27	4.088	4	Frontiers in Earth Science	99	2.9
5	Natural Gas Industry	27	5.915	5	AAPG Bulletin	87	3.5
6	Chinese Petroleum Companies	26	0.141	6	ACTA Geologica Sinica English Edition	69	3.3
7	Petroleum and Natural Gas Geology	25	5.375	7	Energies	69	3.2
8	China Petroleum Exploration	25	8.389	8	ACTA Geologica Sinica	60	1.36
9	Frontiers in Geosciences	15	3.208	9	Geophysics	53	3.3
10	Chinese Petroleum and Chemical Standards and Quality	13	0.51	10	Minerals	53	2.5

\*--2024 comprehensive factor.

On the whole, the number of papers published in international journal is much larger than that in Chinese journals, and there is still much room for progress in the field of deep oil and gas in China.

### 3.3. Analysis of Author Group

#### 3.3.1. High Yield Authors' Publications

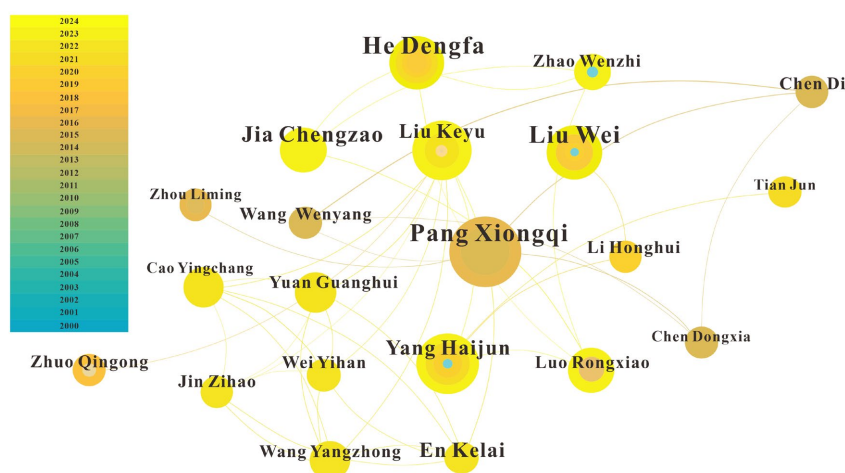
By analyzing the cooperation relationship between authors, we can roughly understand the core authors in the deep oil and gas field, reveal the cooperation mode and network structure of academic research, promote interdisciplinary and inter-institutional cooperation, and improve research efficiency and innovation ability. Through the statistical analysis of the top 10 authors in the field of deep oil and gas (as shown in **Table 2**), it is found that the core research achievements in this field are mainly contributed by a group of outstanding scholars, especially Zhu Guangyou, Liu Keyu and Pang Xiongqi. There are relatively more Chinese scholars, and the top 10 include Zhu Guangyou, Liu Keyu, Pang Xiongqi, Yang Haijun, Lu Shuangfang, He Dengfa and Liu Shugen.

**Table 2.** Top 10 authors in the world with the highest publication volume in the deep oil and gas field.

Serial Number	Author	Country	Institution	Number of publications (articles)
1	Zhu Guangyou	China	China Petroleum Exploration and Development Research Institute	39
2	Liu Keyu	China	China University of Petroleum (East China)	27
3	Pang Xiongqi	China	China University of Petroleum (Beijing)	25
4	Yang Haijun	China	PetroChina Tarim Oilfield Company	22
5	Lu Shuangfang	China	China University of Petroleum (East China)	17
6	Mohammed Hail Hakimi	America	Taiz University	15
7	He Dengfa	China	China University of Geosciences (Beijing)	11
8	Ahmed E Radwan	Poland	Jagiellonian University	9
9	Charles R Fisher	Yemen	Pennsylvania State University	9
10	Liu Shugen	China	Chengdu University of Technology	8

Using CiteSpace software, we set the analysis focus on the “author” node, and run it to generate the author cooperation map (**Figure 2**). In this map, the size of the author’s node directly reflects the number of papers published, that is, the larger the node, the richer the author’s published results. The connection between nodes symbolizes the cooperation between authors. The existence of the connection indicates that there are common research projects or academic exchanges

between these authors. Through in-depth analysis of **Figure 2**, it can be seen that most researchers in deep oil and gas related fields show a trend of collectivization, and have established a relatively close cooperative relationship with each other. According to the map, researchers can be roughly divided into three categories: 1) pairwise cooperative type: researchers connected by two nodes, such as Zhou Liming and Pang Xiongqi, indicate that they have conducted collaborative research between two; 2) Small team type: Jin Zihao, Wei Yihan, Wang Yanzhong and other researchers connected by more than three nodes indicate that they have successfully established a small research team; 3) Large scale research team type: a large-scale research team centered on Liu Keyu, He Dengfa, Pang Xiongqi and Yang Haijun emerged.



**Figure 2.** Relationship diagram of Chinese authors in the field of deep oil and gas research in CNKI from 2000 to 2024.

### 3.3.2. Analysis of the Author's Organization

Through in-depth study of the relationship between the author's institutional system and the number of published papers, we can effectively analyze the geographical distribution characteristics of scientific research forces, and further reveal the actual capabilities and contributions of different systems and institutions in deep oil and gas and other scientific research fields (Gao et al., 2018). To achieve this goal, this study selected the core journals in CNKI as the data source, and selected 672 related articles for analysis. The statistical results show that the authors of these articles are widely distributed in many systems, mainly including professional research institutes, colleges and universities, administrative institutions and other types of scientific research institutions. As can be seen from **Table 3**, the top five institutions with outstanding performance in terms of the number of documents issued are China Petroleum Exploration and Development Research Institute, Sinopec petroleum exploration and Development Research Institute, PetroChina Tarim Oilfield Company, China University of Petroleum (Beijing), and China University of Petroleum (East China). Among them, the number of papers issued by China Petroleum Exploration and Development Research Institute and

Sinopec petroleum exploration and Development Research Institute were 145 and 128 respectively.

**Table 3.** The publication status of the top 15 institutions in the field of deep oil and gas research published by CNKI.

Serial Number	Institution	Number of publications	Proportion
1	China Petroleum Exploration and Development Research Institute	66	28%
2	Sinopec Petroleum Exploration and Development Research Institute	20	9%
3	China University of Petroleum (Beijing)	24	10%
4	China Petroleum Tarim Oilfield Company	17	7%
5	China University of Petroleum (East China)	15	6%
6	State Key Laboratory of Oil and Gas Resources and Exploration	13	6%
7	Exploration and Development Research Institute of Sinopec Shengli Oilfield Branch	11	5%
8	CNOOC (China) Limited Tianjin Branch	10	4%
9	Wuxi Institute of Petroleum Geology, Sinopec Petroleum Exploration and Development Research Institute	9	4%
10	Exploration and Development Research Institute of PetroChina Tarim Oilfield Company	9	4%
11	Sinopec Northwest Oilfield Branch	8	3%
12	China Petroleum & Chemical Corporation Limited	8	3%
13	China University of Geosciences (Beijing)	8	3%
14	Southwest Petroleum University	7	3%
15	China University of Petroleum Basin and Reservoir Research Center	7	3%

The statistical results (as shown in **Table 4**) clearly reveal the core contributors of deep oil and gas research in China. The top 15 authors published 235 articles, accounting for 34.97% of the total number of papers published in this field in China. Zhu Guangyou of China Petroleum Exploration and Development Research Institute published 39 articles on deep oil and gas. Through the analysis of **Table 4**, it can be seen that there are two scholars from China Petroleum Exploration and Development Research Institute, three from China University of Petroleum (East China), one scholar from China University of Petroleum (Beijing) and one scholar from China University of Geosciences (Beijing), and one from PetroChina Tarim Oilfield branch in the top 15. The researchers of these institutes and universities are the leaders in the field of deep oil and gas in China.

**Table 4.** Top 15 Chinese authors in deep oil and gas research publications.

Serial Number	Author	Number of publications (articles)	Institution
1	Zhu Guangyou	39	China Petroleum Exploration and Development Research Institute
2	Liu Keyu	27	China University of Petroleum (East China)
3	Pang Xiongqi	25	China University of Petroleum (Beijing)
4	Yang Haijun	22	PetroChina Tarim Oilfield Branch
5	Zhang Zhiyao	17	China University of Geosciences (Wuhan)
6	Lu Shuangfang	17	China University of Petroleum (East China)
7	Hao Fang	15	China University of Petroleum (East China)
8	He Dengfa	11	China University of Geosciences (Beijing)
9	Jin Zhiyun	11	Peking University Energy Research Institute
10	Zhang Shuichang	10	China Petroleum Exploration and Development Research Institute
11	He Wenjun	10	Development and Research Institute of PetroChina Xinjiang Oilfield Branch
12	Jiang Zaixing	9	China University of Geosciences (Beijing)
13	Liu Shugen	8	Chengdu University of Technology
14	Tuo Jincai	7	Northwest Institute of Ecological Environment and Resources, Chinese Academy of Sciences
15	Wang Xianbin	7	Lanzhou Institute of Geology, Chinese Academy of Sciences

### 3.3.3. Highly Cited Literature by Chinese Authors

The number of citations and the average number of citations per article, as key indicators in citation analysis, not only reflect the ability of academic papers to absorb and integrate external information resources, but also deeply reflect the citation awareness and academic norms of researchers (Zhang, 2016). In order to explore the academic influence and literature value in the field of deep oil and gas research, 20 literatures with the most prominent citation times were selected from CNKI database for in-depth statistical analysis (Table 5). The analysis results show that most of these highly cited articles are review articles written by senior experts in the field, or innovative achievements focusing on the hot topics of early research (Zhang & Wang, 2017). However, it is worth noting that although both of them belong to the high cited category, there are significant differences in the citation frequency between these literatures, with the highest frequency as high as 420 times, while the lowest frequency is only 123 times. This phenomenon not only reflects the fluctuation of literature quality in the field of deep oil and gas research, but also may mean the diversity and complexity of research topics and directions in this field, as well as the difference in the degree of academic recognition of different research results.

**Table 5.** Top 20 frequently cited literature in the field of deep oil and gas research in China.

Serial Number	Author	Title of the Article	Cited frequency
1	Jia et al. (2014)	Prospects and challenges of China's natural gas industry	420
2	Sun et al. (2013)	Formation, distribution and potential prediction of deep oil and gas in China	368
3	Jia et al. (2016)	Research status and development direction of oil and gas resources in China	260
4	Jia and Pang, (2015)	Research progress and main development direction of deep oil and gas geological theory	233
5	Zhu and Zhang, (2009)	Deep hydrocarbon accumulation conditions and exploration potential in China	225
6	Zhang et al. (2015)	Global deep oil and gas exploration and theoretical and technical progress	208
7	Ma et al. (2011)	Review on formation mechanism of deep and ultra deep carbonate reservoirs	203
8	Qi (2016)	Hydrocarbon breakthrough and its significance in Ordovician carbonate rocks of shuntuoguo uplift, Tarim Basin	198
9	Li et al. (2020)	Progress and development direction of deep oil and gas exploration and development in China	190
10	Hao et al. (2002a)	Evolution of overpressure system and deep hydrocarbon accumulation conditions in sedimentary basin	167
11	Zhao et al. (2014)	Further discussion on petroleum geological characteristics and exploration prospects of deep marine carbonate rocks on land in China	156
12	He et al. (2016)	Hydrocarbon accumulation characteristics and exploration fields of marine ultra deep carbonate rocks in China	156
13	Tuo (2002)	Status and progress of deep oil and gas research	154
14	Shi et al. (2005)	Exploration prospect analysis of deep oil and gas reservoirs	151
15	Hao et al. (2002b)	Research progress and frontier research fields of hydrocarbon accumulation mechanism	145
16	Bai et al. (2014)	Global deep reservoirs and their distribution	139
17	Yang et al. (2020)	Great discovery and significance of ultra deep oil and gas exploration in luntan-1 well in Tarim Basin	137
18	Zhang et al. (2014)	Formation mechanism of ultra deep low porosity tight sandstone reservoir and its significance for oil and gas exploration in Kuqa Depression	136
19	Liu et al. (2016)	Characteristics of deep microbial carbonate reservoirs and their oil and gas exploration prospects in Sichuan Basin	124
20	Su et al. (2020)	Status quo of drilling and completion technology for onshore deep and ultra deep wells in China and suggestions for tackling key problems	123

### 3.4. Keyword Analysis

Using the “burst detection” hot spot diagnosis function of CiteSpace software, we can effectively identify and analyze the dynamic changes in hot topics, literature, authors and journal citation information that have risen rapidly in a short period of time (An et al., 2018). This function module outputs the burst index by calculating the explosive characteristics of each node (such as keywords), which directly reflects the rapid growth of the node in a specific period of time; At the same time, the strength value quantifies the intensity of the emergence, that is, the strength of the high-frequency citation of the word in a short time.

Based on the above analysis, we can divide the evolution of research hot-spots in the deep oil and gas field into the following three stages (as shown in **Figure 3**). 1) The first stage (1996-2004): this stage witnessed the high-frequency emergence and long-term sustained influence of multiple keywords. These keywords not only have a long outbreak cycle but also have a high centrality, indicating that they are the topics that continue to be widely discussed by researchers during this period. Since 2004, keywords such as “deep exploration”, “application” and “Biyang depression” have rapidly emerged as new research hot-spots. Among them, “deep exploration” is particularly prominent with its highest intensity, indicating that the research focus in this period is on the exploration technology of deep oil and gas. 2) The second stage (2006-2018): there are some new keywords in this stage. Although they have a long explosion cycle, their relative explosion degree is low, such as “reservoir forming conditions”, “exploration prospects” and “structural characteristics”. These keywords point more to the theoretical research on the process of system change and evolution law, reflecting that researchers have begun to explore the formation mechanism, exploration potential and geological structure characteristics of deep oil and gas reservoirs. 3) The third stage (2019 to now): entering this stage, new explosive words such as “ultra deep”, “Sichuan Basin” and “Dongying depression” have emerged one after another. These words not only represent the latest focus of current research, but also indicate the trend of deep oil and gas exploration towards deeper and more complex geological conditions. In particular, the proposal of “ultra deep” reflects the challenge and exploration of oil and gas resource exploration technology under extreme conditions.

### 3.5. Funding

As an important driving force for scientific research and exploration, the funding status of funded projects is a key indicator for evaluating the degree of attention paid to a research field and the intensity of resource investment (Cao & Zhao, 2019). In order to deeply understand the fund support pattern and development trend of China’s deep oil and gas research field, we have made a detailed statistics of the fund support in this field (As shown in **Figure 4**). The statistical results show that in the 685 deep oil and gas related literatures analyzed, a total of 277 fund projects have provided support, of which the national fund occupies the dominant position.

### Top 25 Keywords with the Strongest Citation Bursts

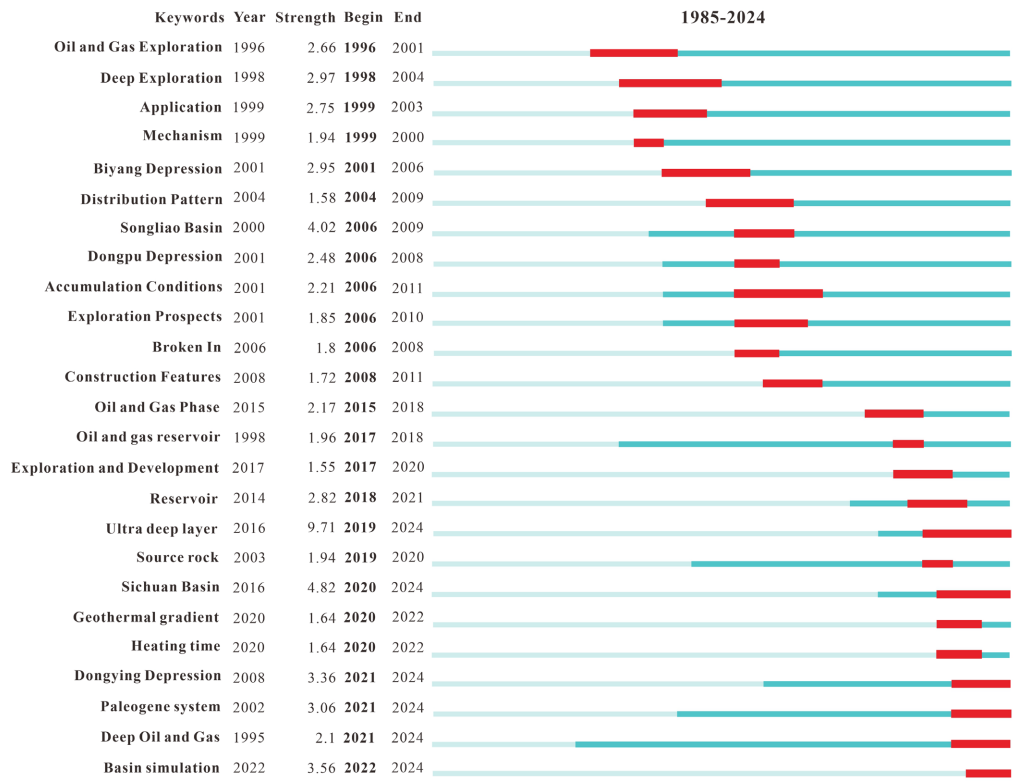


Figure 3. High frequency keyword emergence detection map in the field of CNKI deep oil and gas research from 1985 to 2024.

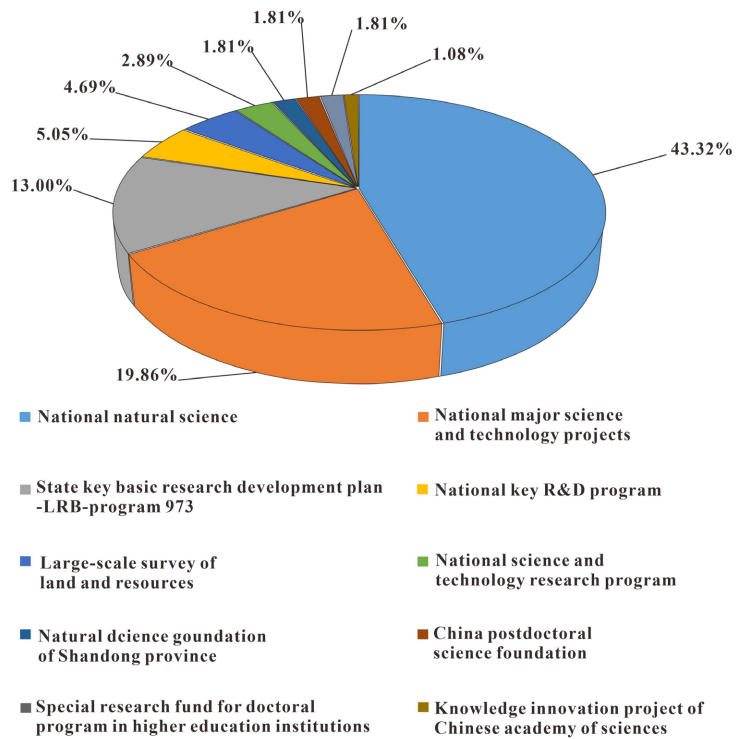


Figure 4. Supported by the china deep oil and gas research fund.

Specifically, the number of research articles funded by National Natural Science Foundation of China, major national science and technology projects, national key basic research and development plan (973 Plan), national key research and development plan, national land and resources survey project, National Science and technology research and development plan, national high technology research and development plan (863 plan), National College Students' innovation and entrepreneurship training program, and national key laboratory project is as high as 250, accounting for 36.5% of the total amount of literature. This data clearly shows that the national level attaches great importance to and vigorously supports deep oil and gas research. In addition, we have also noted the contributions of other funding sources, including special funds for colleges and universities and local natural science funds. Among them, the special scientific research fund for doctoral programs in Colleges and universities supported 5 papers, accounting for about 0.7%; The knowledge innovation project of the Chinese Academy of Sciences funded three papers, accounting for about 0.4%. Provincial funded projects have also played a positive role, with 11 papers published, accounting for 1.6% of the total. These projects are mainly from the Natural Science Foundation of Shandong Province (5 papers, accounting for 0.7%), the Natural Science Foundation of Heilongjiang Province (3 papers, accounting for 0.4%) and the Natural Science research project of the Department of Education of Shanxi Province (2 papers, accounting for 0.3%).

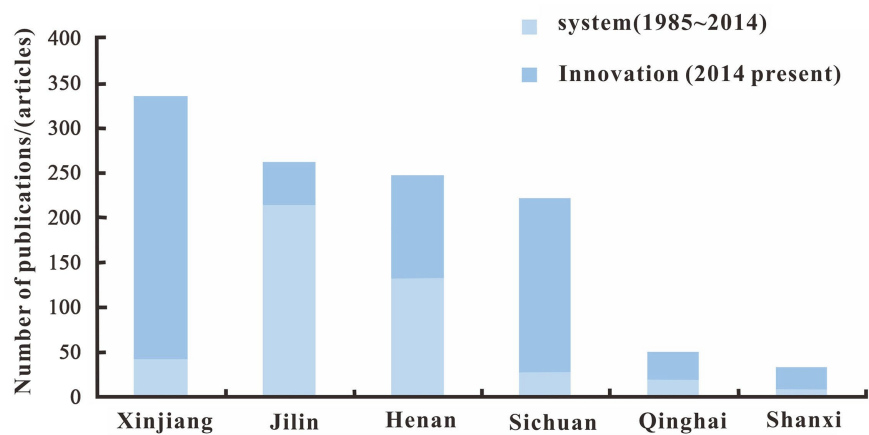
The main force of deep oil and gas research in China is concentrated at the national level, while the provinces' direct research investment in this field is relatively small. This phenomenon is closely related to the research focus and resource allocation of universities and scientific research institutes in each province. For example, Shandong Province and Heilongjiang Province have two universities with significant influence in the deep oil and gas field, China University of Petroleum (East China) and Northeast Petroleum University, respectively, so there are many related fund-funded projects. This analysis further reveals the regional characteristics and institutional distribution characteristics of deep oil and gas research in China.

## 4. Discussion

### 4.1. Changes in the Study Area

Through the analysis of spatial scale, we can clearly observe the focus change and transfer trajectory of the study area in the deep oil and gas field (Chen & Wang, 2018). **Figure 5** shows the statistics of the study area from 1985 to 2024, revealing the wide distribution and dynamic evolution of research activities. In the early stages (1985-2014), research activities were mainly concentrated in Jilin, Henan, and other places. This period can be regarded as the initial stage of system development. The research area has not yet formed a comprehensive network, but has begun to take shape. With the deepening of research, especially in the innovation and development stage from 2004 to 2022, the research area began to show an

obvious transfer trend, gradually expanding from the traditional Jilin, Henan and other places to Xinjiang, Sichuan and other regions. This change not only reflects the geographical shift of research focus, but also indicates that a new hot spot of deep oil and gas exploration is forming, that is, a diversified research pattern with Xinjiang and Sichuan as the core and Henan, Jilin and other regions as the focus. The reasons for this situation may be as follows: 1) resource distribution and exploration potential: the distribution of deep oil and gas is not uniform, and the geological conditions and especially the degree of enrichment in different regions are quite different. Compared with Jilin, Henan and other regions, the oil and gas resources in Xinjiang, Sichuan and other regions may be buried deeper and the geological conditions are more complex, but this also means that these regions have greater exploration potential. 2) Improvement of scientific research and innovation ability: with the continuous breakthroughs in key technologies such as seismic exploration, drilling technology and hydrocarbon accumulation theory, it is possible to carry out deep oil and gas exploration under complex geological conditions.



**Figure 5.** Document issuance in different stages and research areas.

It can be seen from **Table 6** that the research on the deep oil and gas field of Paleogene in China is mainly concentrated in Henan Province and Shandong Province. The lower Tertiary, Cambrian and Jurassic are respectively concentrated in Dongpu depression, Dongying depression, Sichuan Basin, Xinjiang Tarim Basin, Junggar basin, Qinghai Qaidam Basin. Sinian, Ordovician, Cretaceous and Neogene are mainly concentrated in Sichuan Basin, Xinjiang Tarim Basin, Junggar Basin and Qinghai Province. The Permian system is mainly located in the southwest and northwest of China.

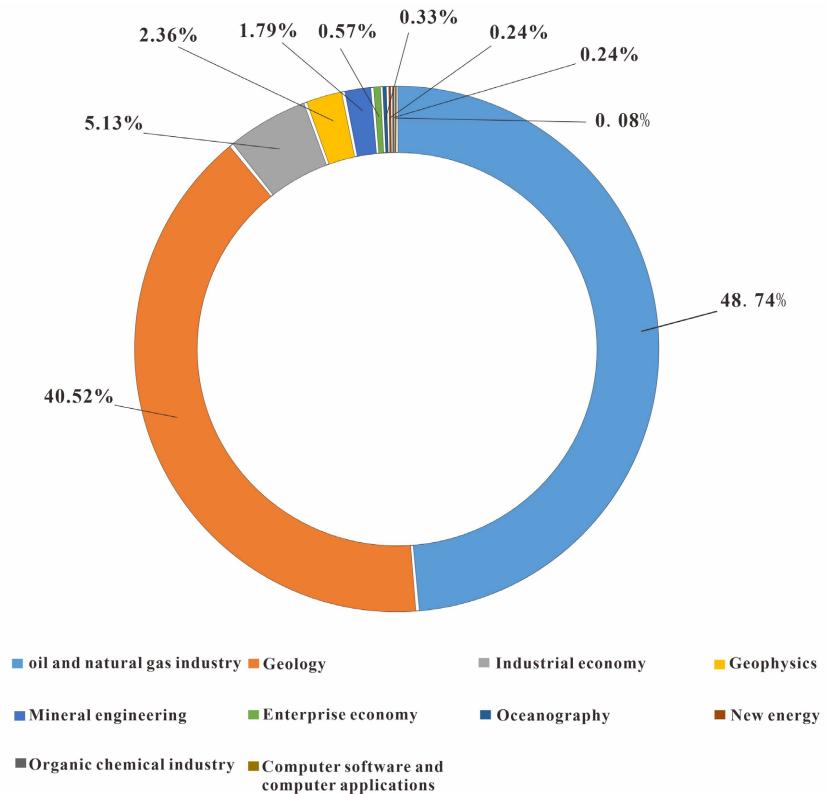
#### 4.2. Analysis of Research Disciplines

The disciplines related to the deep oil and gas field are mainly geology and Geophysics, petroleum and natural gas industry, mining engineering and other disciplines (**Figure 6**), of which the relationship with petroleum and natural gas industry and geology is the closest. In recent years, it has also expanded to the fields of

new energy, organic chemical industry, oceanography, computer software and computer applications.

**Table 6.** Table of key research content by region.

Area	Study area Study stratum	Author (time of issue)	Main research institutions	
Henan	Dongpu depression	Paleogene	Wang et al. (2006); Wang et al. (2023)	China University of Geosciences (Beijing); Zhongyuan Oilfield geophysical prospecting company
		Lower Tertiary	Zhou et al. (2004); Yang et al. (2003)	
Xinjiang	Tarim Basin	Ordovician	Zhu et al. (2020); Ma et al. (2020)	China Petroleum Exploration and Development Research Institute
		Cambrian	Gu et al. (2019); Zhu et al. (2012)	
	Jurassic system	Mao et al. (2020); Sun et al. (2022)		
	The Junggar Basin	Permian system	Tang et al. (2022); Shan et al. (2024)	
		Cretaceous system	Meng et al. (2022); Gao et al. (2023)	
Shanxi	Ordos Basin	Permian	Cao et al. (2024)	PetroChina Changqing Oilfield Company
Sichuan	Sichuan Basin	Permian	Ma and Cai (2006); He et al. (2024)	China Petroleum Exploration and Development Research Institute; Chengdu University of Technology
		Sinian system	Liu et al. (2016, 2021); Zhao et al. (2020)	
		Ordovician Silurian	Nie et al. (2022); Duan et al. (2019)	
		Cambrian	Gong et al. (2024); Li et al. (2024)	
Shandong	Dongying depression	Lower Tertiary	Yuan and Wang (2001)	China University of Petroleum (East China)
		Paleogene	Wang (2010); Zhang et al. (2008)	
Qinghai	Qaidam Basin	Jurassic System	Wang et al. (1997); Wu et al. (2023)	Exploration and Development Research Institute of PetroChina Qinghai Oilfield Company
		Neogene	Zhao et al. (2015); Zeng et al. (2015)	



**Figure 6.** Discipline distribution of deep oil and gas research.

In recent years, Chinese scholars have made some achievements in deep-ultra-deep applied basic research and technical research. According to the exploitation characteristics of deep shale oil and gas, bg125hc high-strength heterogeneous load resistant casing was developed (Dong et al., 2024). The prediction method of reservoir oil and gas productivity before oil test for the ultra deep Cambrian dolomite reservoir in Tarim Basin was introduced, and the evaluation standard of reservoir oil and gas potential in this area was formed (Ding et al., 2024). By analyzing the U-Pb isotopic dating results of carbonate cement primary oil inclusions and carbonate veins, the veins filled by the reservoir in Fuman oilfield are determined, which improves the understanding of the hydrocarbon accumulation mechanism and hydrocarbon enrichment law of deep ultra deep carbonate rocks (Huang et al., 2024).

With the progress of deep oil and gas exploration and development technology, this field is gradually integrated with various disciplines, and a series of novel research directions are combined. Yao et al. (2024) linked deep oil and gas with computer science and numerical simulation technology, and proposed a digital core reconstruction method based on discrete element method considering the influence of high stress, to construct digital cores under different stresses. The research results show that with the increase of stress, the radius of pores and throats in the core will be significantly reduced, the throat will be extended, the porosity and permeability will be reduced, which provides a technical route for pore scale simulation of deep and ultra deep oil and gas reservoirs. Yan et al.

(2020) proposed that adamantane compounds exhibit excellent thermal stability and biodegradation resistance due to their unique cage molecular structure, showing broad application potential in the field of deep oil and gas exploration. In depth study of the baseline characteristics of methyl double adamantane in crude oil samples from different sedimentary basins, and expand and deepen the application scenarios of adamantane compounds in actual exploration. This study not only helps to fill the gap in the application field of adamantane compounds, but also provides important clues for in-depth understanding of the formation mechanism of deep oil and gas reservoirs, which is of great significance to guide the future deep oil and gas exploration.

## 5. Conclusion

Using CiteSpace software and bibliometric methods, this paper conducts in-depth knowledge map construction and analysis of the literature on deep oil and gas field in CNKI Chinese core journals from 1985 to 2024, aiming to reveal the research hot-spots, core author groups, distribution of important journals and major research institutions in this field, so as to comprehensively grasp the research status and development trend.

The analysis results show that the main authors who have done more research in the field of deep oil and gas in China are Zhu Guangyou, Liu Keyu, Pang Xiongqi, Yang Haijun, Lu Shuangfang and so on. Their research achievements have played a key role in promoting the development of this field. From the perspective of the overall pattern, China's deep oil and gas research shows the characteristics of "overall coordination and local independence", that is, most research teams have strong links and cooperation, but some teams have not yet formed a direct collaboration network, which suggests that cross team communication should be strengthened in the future to promote knowledge sharing and collaborative innovation. It is worth noting that most of the research teams are composed of members of the same institution, indicating that there is close cooperation within the institution, while there is still room for improvement in academic exchanges and cooperation between institutions.

In terms of document issuing institutions, China Petroleum Exploration and Development Research Institute ranks first with significant advantages, followed by Sinopec petroleum exploration and Development Research Institute and China University of Petroleum (Beijing), which shows the profound heritage and important contributions of these institutions in the field of deep oil and gas research. From the perspective of journal distribution, "Acta Petrologica Sinica" has become the main place for the publication of articles in this field. At the same time, journals such as "Natural Gas Geoscience", "Oil Exploration and Development", "Petroleum Experimental Geology" and "Natural Gas Industry" also carry a large number of high-quality research results, providing an important platform for academic exchange and knowledge dissemination.

Key words analysis reveals many hot spots and focuses of deep oil and gas

research, such as the study of geographical regions such as “Biyang depression” and “Songliao Basin”, theoretical exploration such as “reservoir forming conditions” and “exploration prospects”, as well as the analysis of geological characteristics such as “hydrocarbon source rock” and “Paleogene”. In terms of research funding, the national fund occupies a dominant position, accounting for 36.5%, highlighting the high attention and support of the national level for deep oil and gas research.

From the perspective of regional distribution, the study of deep oil and gas in Paleogene is particularly concentrated in Henan and Shandong Province, while the study of oil and gas in different geological periods such as lower Tertiary, Cambrian and Jurassic is all over the budongpu depression, Dongying depression, Sichuan Basin, Xinjiang Tarim Basin, Junggar Basin and Qinghai Qaidam Basin, showing diversified regional characteristics.

Facing the changes of the situation at home and abroad, the deep oil and gas research is facing new challenges and opportunities. In the future, this field should focus on technological innovation and cost reduction and improve the efficiency and success rate of exploration and development through the research and development of new technologies, new processes and new equipment. At the same time, strengthen team cooperation and resource sharing, and jointly deal with the technical problems and financial challenges in the development of deep oil and gas resources through cross-agency and cross-border cooperation. In addition, promoting the application of intelligent technology in oil and gas exploration and development will also become an important direction of future research.

### **Acknowledgements**

The Postgraduate Innovation and Practice Ability Development Fund of Xi’an Shiyou University (YCS23213072).

### **Conflicts of Interest**

The authors declare no conflicts of interest regarding the publication of this paper.

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